U.S. ATLAS HL-LHC Upgrade Science Flowdown & Technical Overview

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NSF Conceptual Design Review of the U.S. ATLAS HL-LHC Upgrade
National Highway Institute
Arlington, Virginia
March 8-10, 2016

U.S. ATLAS HL-LHC Technical Coordinator

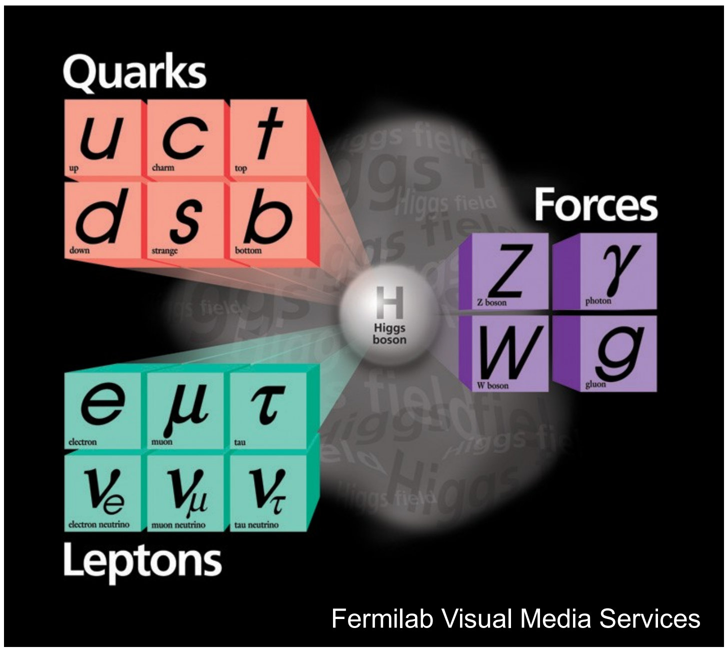
- Hal Evans: Professor, Indiana University
  - UA1, OPAL, D0, ATLAS experiments
  - U.S. ATLAS HL-LHC Technical Coordinator since Dec. 2014
- Specializations
  - Trigger Systems
  - B-Physics, Exotic Higgs, Vector Boson Scattering, Lorentz Violation
- Previous Management Experience
  - U.S. ATLAS
    - Phase-I: TDAQ (deputy) Manager (Level-2)
    - Operations: M&O Manager (Level-1), TRT Manager (L2), TDAQ R&D (L2)
  - ATLAS
    - Inner Detector Institute Board Chair, TRT IB Chair
    - B-->J/psi Physics sub-group convenor
  - D0
    - Run2b Trigger Upgrade co-Manager, Run2b L1Calo Upgrade co-Manager, Run2 Muon Level-2 Trigger co-Leader, Run2 Silicon Track Trigger co-Leader
    - B-Physics Working Group Convenor

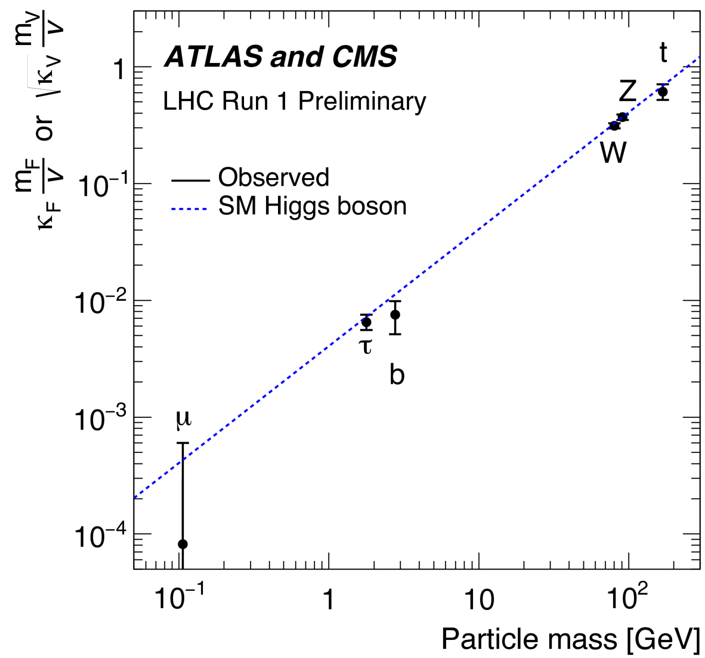
Outline

- Motivation for the HL-LHC Upgrades
  - Science Goals, Science Requirements
  - Technical Motivation
- Overview of the ATLAS HL-LHC Upgrade
  - Focus on proposed NSF Scope
  - Flowdown from Science Goals to Scope
- Ongoing R&D Effort in the U.S.
- Technical Risks and Contingency

State of the Art

- The Standard Model is now well established
  - 2012 discovery of the Higgs Boson by ATLAS, CMS ==> Nobel Prize

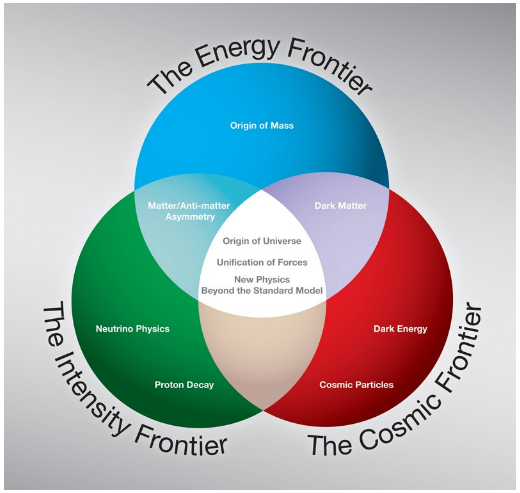




- LHC program has played a major role (not just the Higgs)
  - >500 ATLAS publications

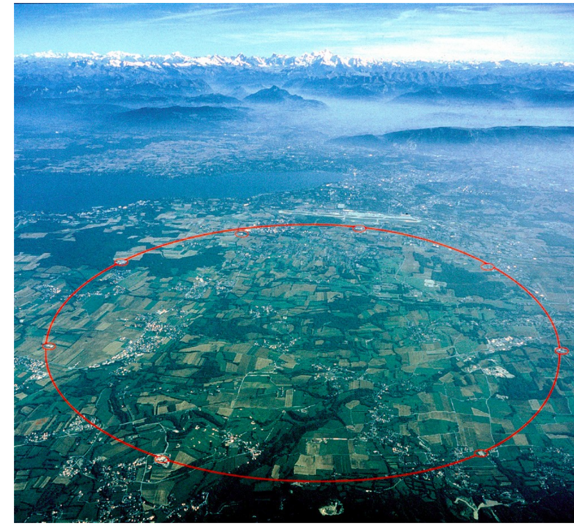
Big Questions Remain

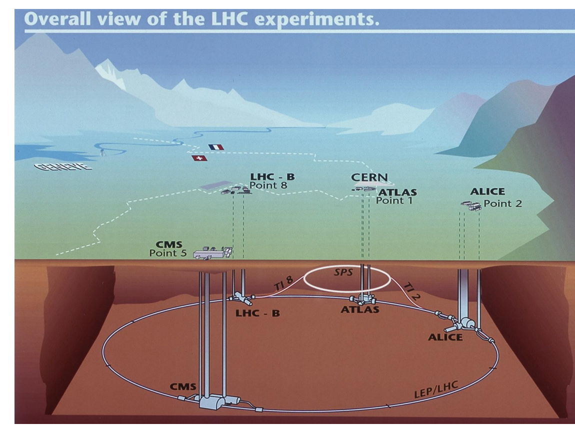
- P5 Science Drivers ==> Major Goals of HEP
  - Use the Higgs boson as a new tool for discovery
  - Pursue the physics associated with neutrino mass
  - Identify the new physics of dark matter
  - Understand cosmic acceleration: dark energy and inflation
  - Explore the unknown: new particles, interactions, and physical principles
- Multiple approaches needed: Energy, Intensity, Cosmic Frontiers
- Energy Frontier contributions
  - general purpose experiments at colliders are an important tool
  - wide range of measurements ==> understand correlations



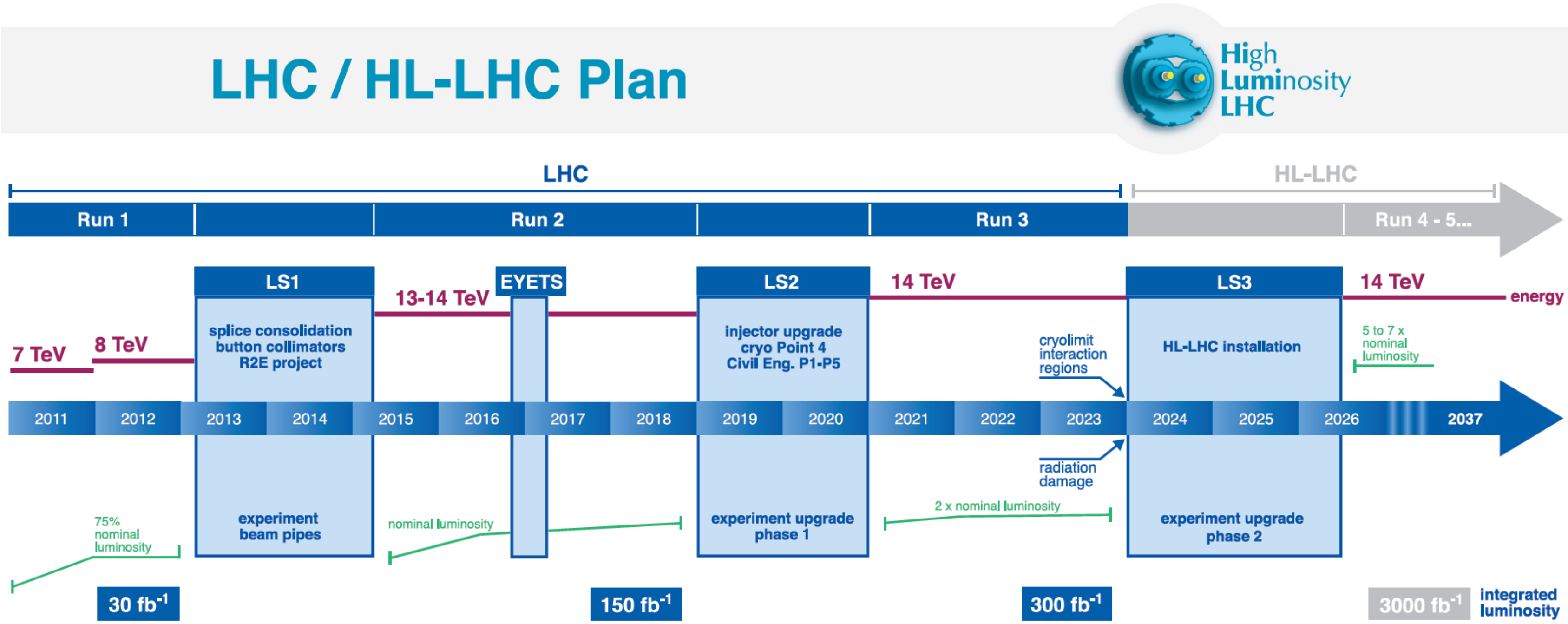
Getting to the Answers

- Basic Collider tools
  - Energy ($\sqrt{s}$): produce higher mass objects
  - Intensity (luminosity): produce rare processes
- Highest energy collisions currently at the LHC
  - general purpose experiments ATLAS & CMS
    - ~25 fb^{-1} at $\sqrt{s}$ = 7,8 TeV ==> ~2×10^{15} pp collisions
    - + ~4 fb^{-1} at $\sqrt{s}$ = 13 TeV
  - note: N = cross-section × integrated luminosity
    - cross-section units = area (1 fb = 10^{-15} b = 10^{-39} cm^2
    - (time) integrated luminosity units – area^{-1}
- Time to collect more statistics
  - assuming best 8 TeV LHC conditions
    - 20 fb^{-1} per year
    - ==> 10 years to increase dataset x10
    - ==> 100 years to increase dataset x100
    - note: factor 10 increase in dataset ==> factor 3.2 better meas. accuracy
  - clearly impractical ==> need to improve 20 fb^{-1} per year





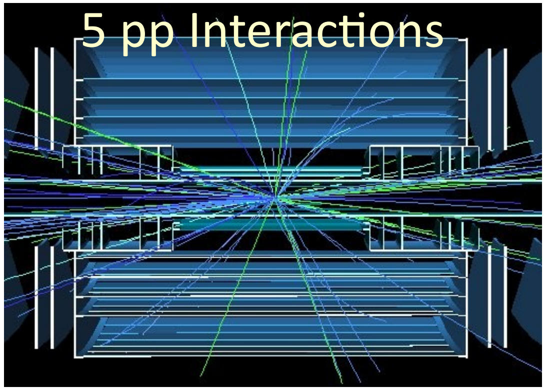
LHC Plans to Provide Data

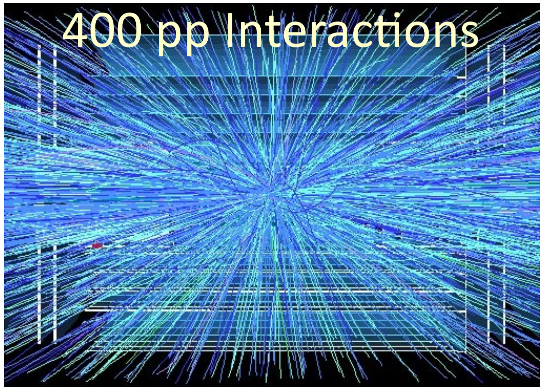


Run	Years	Energy (TeV)	Bunch Spacing (ns)	Peak Lumi (x 10^{34} cm^{-2} s^{-1})	Pileup (pp collisions/crossing)	Total Int. Lumi (fb^{-1})
1	2010-12	7,8	50	0.75	20	30
2	2015-18	13,14	25	1.6	43	150
3	2021-23	14	25	2-3	50-80	300
4...	2026...	14	25	5-7.5	140-200	3,000

LHC 101

- <u>Collisions</u> at the LHC (14 TeV center of mass energy)
  - LHC beams: ~2700 "bunches" of protons (2.2×10^{11} protons/bunch) in each beam
  - bunches cross in the center of ATLAS every 25 ns – each bunch crossing = an <u>Event</u>
- <u>Pileup</u>: at high luminosity each Bunch Crossing ==> multiple p-p collisions
  - number of p-p interactions/crossing is random (Poisson process)
    - mean is a function of luminosity





Significant Challenges for the Detector

Quantity	25 pp interactions/crossing	200 pp interactions/crossing
Tracks (p_T>500MeV, $\|\eta\|$<2.5) (η = measure of angle from beamline)	375	3,000
Median Energy Density in Jets	22 GeV/rad^2	175 GeV/rad^2

HL-LHC Science Opportunites

- HL-LHC focuses on 3 of 5 P5 Science Drivers
  - Use the <u>Higgs</u> boson as a new tool for discovery (probe electro-weak symmetry)
  - Identify the new physics of <u>Dark Matter</u> (makes up ~26% of the universe's mass-energy)
  - Explore the <u>Unknown</u>: new particles, interactions, and physical principles (SUSY, extra dimensions,...)
- Broad ATLAS physics program addresses these
  - ATLAS Physics Working Groups look at Standard Model and Beyond from many perspectives
    - Heavy Ions, B-Physics & Light States, Standard Model, Top, Higgs, Supersymmetry, Exotics
- ATLAS has studied several example channels in detail
  - to assess sensitivity with x100 more data (3,000 fb^{-1}) than currently available

Higgs + Unknown

Dark Matter + Unknown

Higgs + Unknown

Channel	Example Quantity	Run 1 Result (up to $25fb^{-1}$)	Target HL-LHC Sens. (3000 fb^{-1})
$H \rightarrow 4\mu$	Relative uncertainty on production	22%	2.2%
VBF $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$	Relative uncertainty on production	360%	17% (7.6σ)
VBF $H \rightarrow WW^{(*)} \rightarrow \ell\nu\ell\nu$	Relative uncertainty on production	36% (3σ)	14% (8.0σ)
VBS ssWW	Relative uncertainty on production	34% (3.6σ)	5.9% (11σ)
SUSY $\chi_1^{\pm} \chi_2^{0} \rightarrow \ell bb + X$	Chargino/Neutralino mass	>250 GeV (95% CL)	850 GeV (5σ observation)
$HH \rightarrow 4b$	K-K graviton production	---	4.4σ (at M = 2 TeV)

Science Goals

SCIENCE GOALS	SCIENCE REQUIREMENTS	NSF SCOPE
$H \rightarrow 4\mu$ (2.2%) VBF $H \rightarrow ZZ^*, WW^*$ (17%,14%) VBS ssWW (5.9%) SUSY $\chi_1^\pm \chi_2^0 \rightarrow \ell bb+X$ (850 GeV)		
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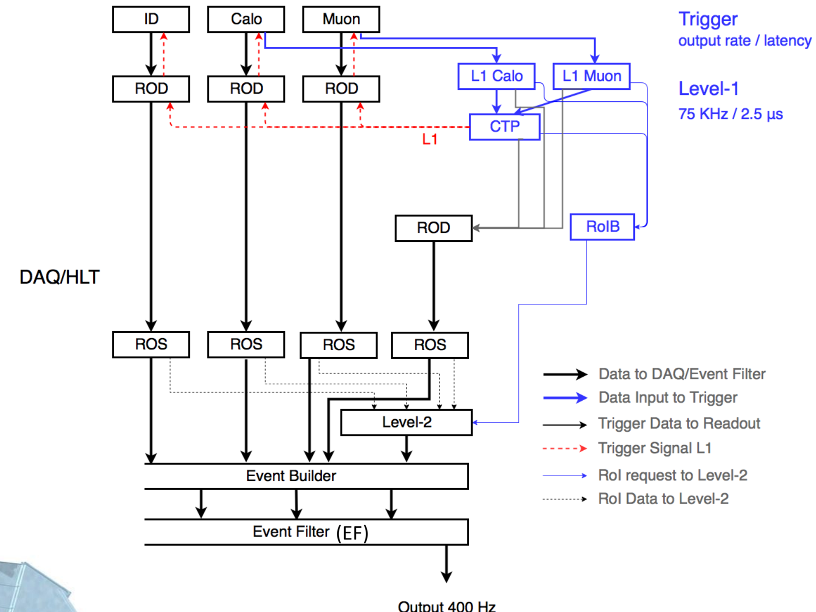
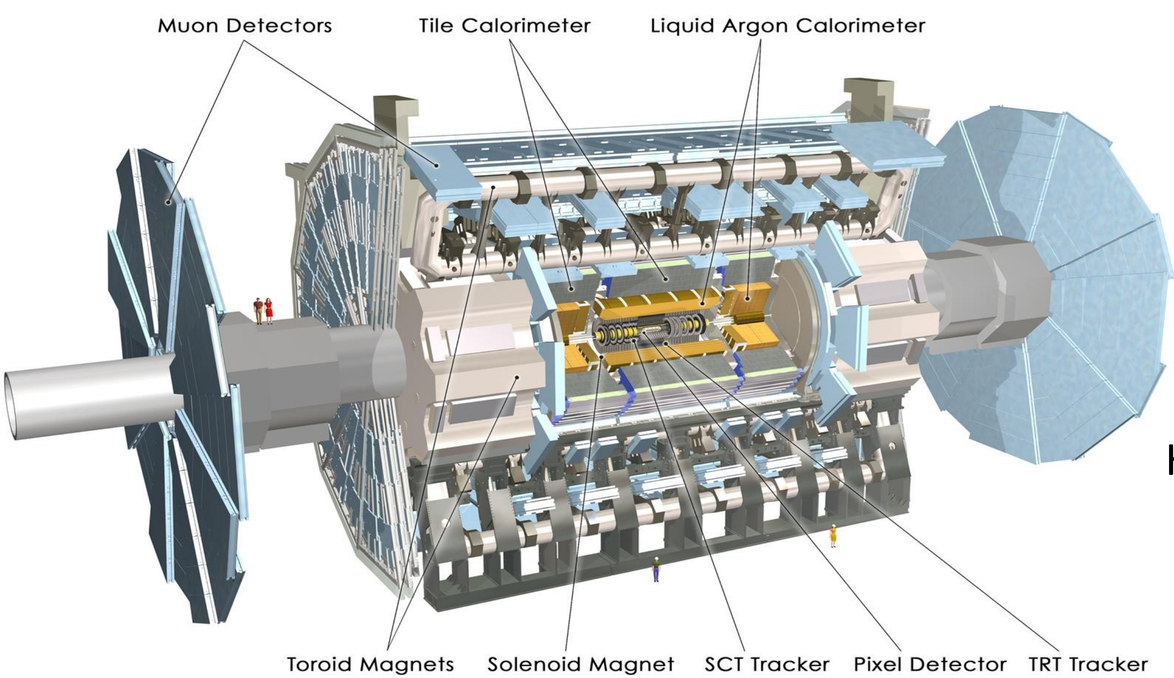
$HH \rightarrow 4b$ (4.4σ KK Graviton)		
Compressed SUSY ($\chi_1^\pm \chi_2^0$)		

ATLAS in 2012

2012 ATLAS Detector

- Inner Detector: charged particle tracking
- Calorimeters: energy measurements
- Muon: muon identification
- Forward: luminosity, diffractive physics
- Magnets: 2Tesla solenoid (track), toroid (muon)





2012 Trigger/DAQ

- 3-Level System
  - L1: custom hardware
  - L2: software (regional)
  - EF: software (full detector)
- Data Acquisition
  - 400 Hz to tape

HLT

ATLAS Evolves with the LHC

- ATLAS must change to benefit from increasing LHC luminosity
  - tracking system: higher track multiplicity, radiation damage
  - trigger system: more complex events
  - readout: larger event size, more bandwidth
  - unchanged: Liquid Argon & Tile calorimeter detectors, most muon detectors

Upgrade	Shutdown	LHC Luminosity Target	Main ATLAS Changes
Phase-0	2013-15	1.6 × design*	• new inner tracking layer (IBL) • forward muon system: detectors + readout • trigger: topology at L1, streamlined dataflow
Phase-I	2019-21	2-3 × design*	• trigger: more info at L1, tracks at start of HLT (FTK) • calorimeter electronics for trigger • new forward muon detectors for trigger (NSW) • more performant readout system
HL-LHC (Phase-II)	2024-26	5-7.5 × design*	• new all-silicon tracking system • some new muon chambers • all new readout electronics: calorimeters, muons • new trigger architecture (L0/L1) + new systems • higher bandwidth readout system • new detectors in forward region (sFCAL, HGTD, μ-Tagger)

* Original Luminosity Target = 1×10^{34} cm^{-2} s^{-1}

HL-LHC Constraints on ATLAS

- pre-HL-LHC ATLAS Detector cannot realize HL-LHC Physics Opportunities
- Technical Motivations (summary)
  - Accumulated Radiation Dose ==> current Inner Detector inoperable
    - integrated charge also causes problems for some Muon detectors
  - High Instantaneous Luminosity ==> complex events
    - 200 pileup collisions per bunch crossing: x7.5 larger than current design
    - particularly an issue for the lowest level triggers
  - Rate + Complexity ==> x10 data volume increase
    - data acquisition & computing infrastructure must deal with this
- Performance Motivations (summary)
  - Efficient Object Reconstruction with Low Background in HL-LHC environment
    - objects (e, μ, τ, jets, *b*-jets, missing energy,...) are the basic building blocks of physics analyses

Science Requirements

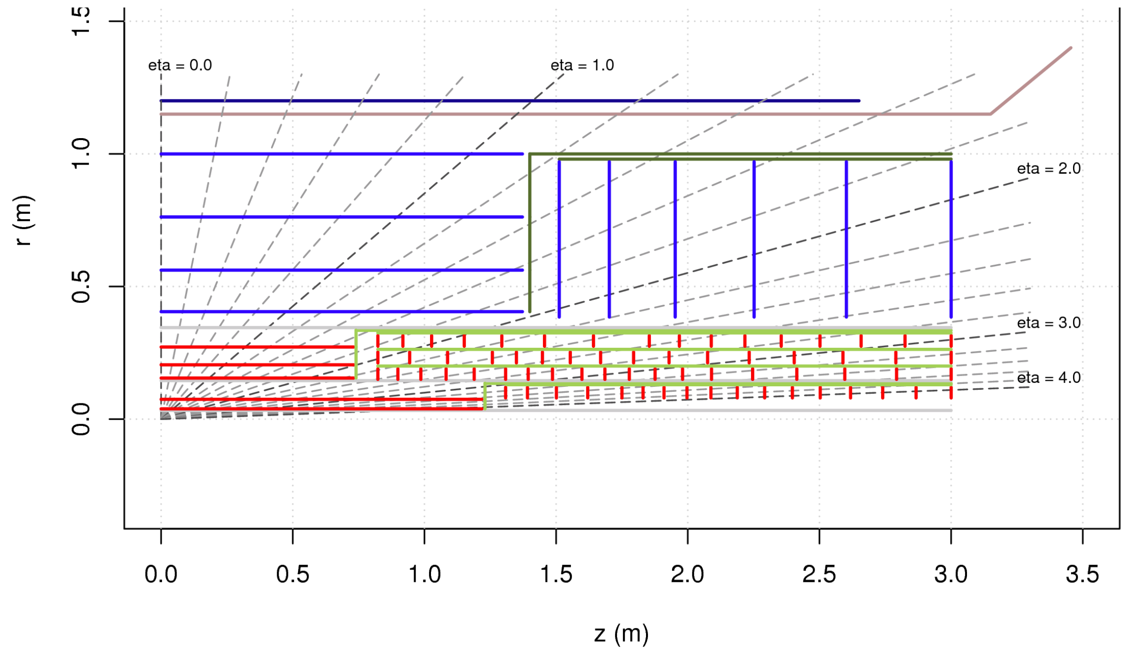
- Basic Goal
  - maintain performance of object (e,μ,τ,jet,E_t^{miss},...) identification/reconstruction at Run-1 levels in the challenging HL-LHC environment
- Impact on Detector & Trigger
  - charged particle tracking that maintains Run-1 levels of performance
    - tracking required for identification/reconstruction of all objects
    - main requirements: resolution, coverage
  - trigger selection of events for permanent storage that maintains at least Run-1 levels of efficiency for interesting physics processes
    - events not selected by the trigger are lost forever
      - low trigger efficiency ==> longer running time to achieve same sensitivity
    - main requirements: sophisticated algorithms, high bandwidth
  - data acquisition (DAQ) and data handling that must deal with data volumes more than an order of magnitude larger than those encountered in Run-1
    - main requirement: bandwidth capacity
- Upgrade proposal that meets Science Goals in a cost-effective way
  - developed after extensive study by entire collaboration ==> Scoping Document (docDB #45)
  - very positively reviewed by independent CERN technical & oversight committees

Science Requirements Summary

SCIENCE GOALS	SCIENCE REQUIREMENTS	NSF SCOPE
$H \rightarrow 4\mu$ (2.2%) VBF $H \rightarrow ZZ^*, WW^*$ (17%,14%) VBS ssWW (5.9%) SUSY $\chi_1^\pm \chi_2^0 \rightarrow \ell bb$+X (850 GeV)	Muon Trigger • single μ p_T threshold ~ 20 GeV • geometric accept: 95% (barrel)	
VBF $H \rightarrow ZZ^*, WW^*$ (17%,14%) VBS ssWW (5.9%) SUSY $\chi_1^\pm \chi_2^0 \rightarrow \ell bb$+X (850 GeV)	Electron Trigger • single e p_T threshold ~ 22 GeV	
$HH \rightarrow 4b$ (4.4σ KK Graviton)	Jet Triggers • 4-jet E_T threshold ~ 75 GeV • "fat" jet threshold ~ 375 GeV • jet-vertex confirmation at L1	
Compressed SUSY ($\chi_1^\pm \chi_2^0$)	Missing E_T Trigger • ME_T threshold ~ 200 GeV • track-based ME_T correction	

Overview of ATLAS HL-LHC Upgrades

- Tracking System (not NSF scope)
  - complete replacement of current Inner Detector with a new all-silicon Inner Tracker (ITK)
    - pixels and strips
    - coverage to $|\eta|=4.0$
  - all-new electronics
    - allows operation with new trigger architecture
    - input to Level-1 Tracking Trigger

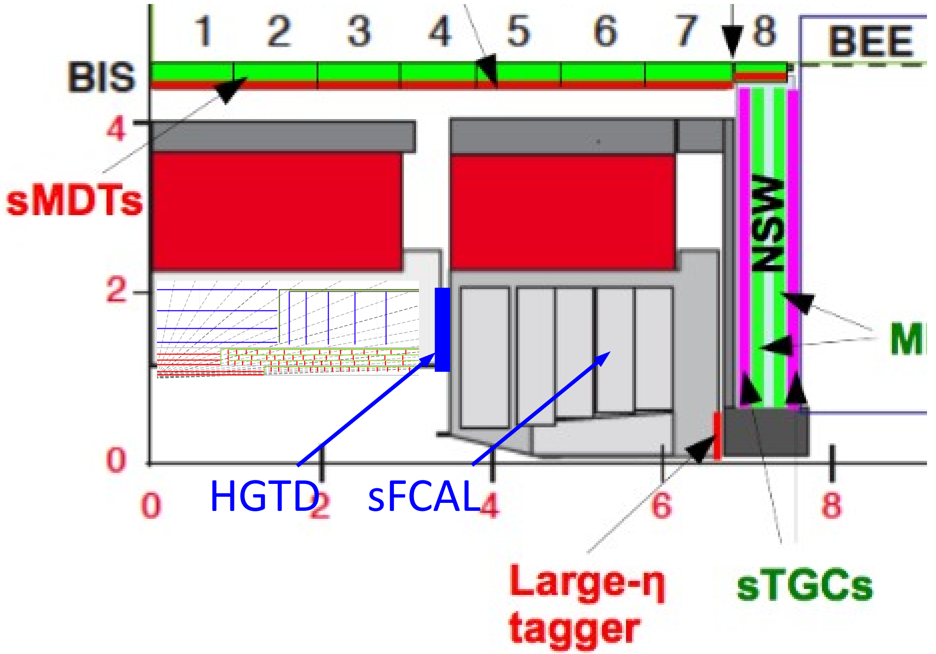


Layout changed from Scoping Document

- 4(pixel) + 5(strip) ==> 5(pixel) + 4(strip) layers

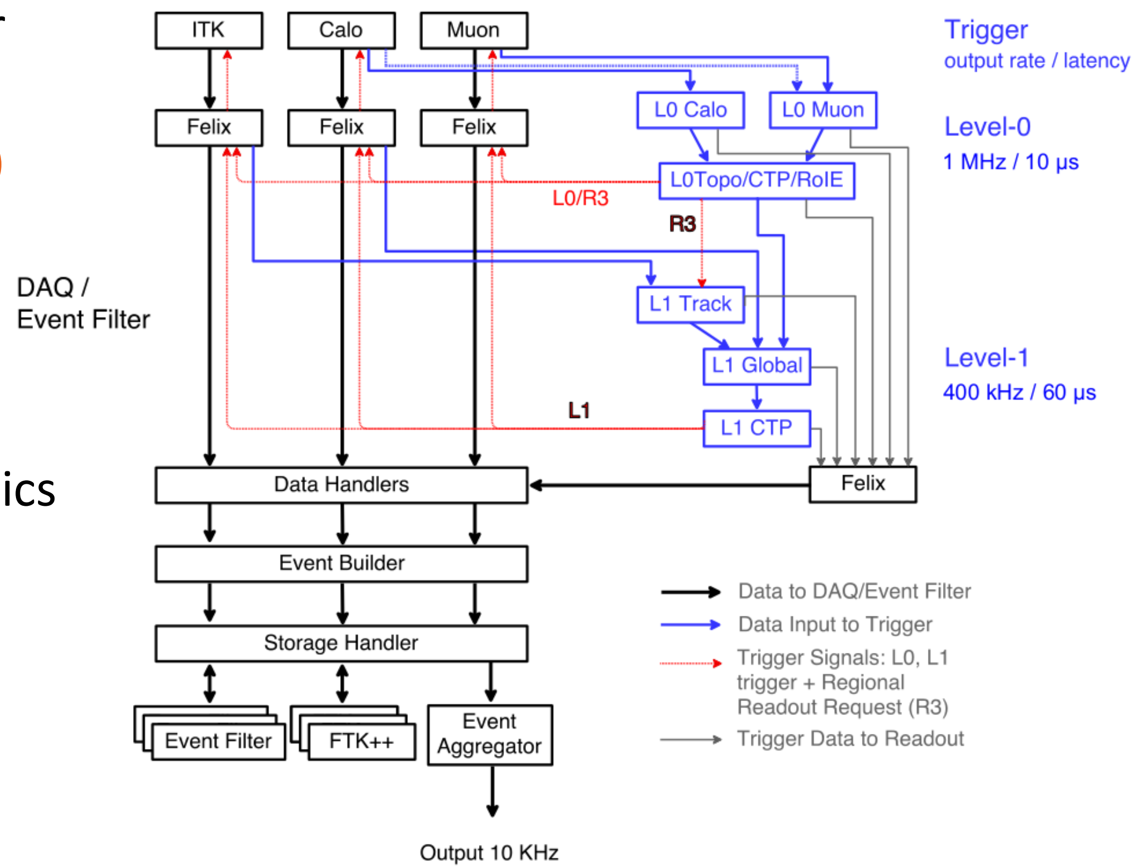
ATLAS HL-LHC Upgrades (2)

- Hardware in the Forward Region (not baseline NSF scope)
  - replace Forward Calorimeter with high-granularity sFCAL
    - improved jet/E_T^{miss} and electron performance
  - add High Granularity Timing Detector (HGTD)
    - $2.3 < |\eta| < 4.3$
    - pileup rejection in poorly covered region
  - add Very Forward Muon Tagger (Large-η Tagger)
    - extend muon coverage to $|\eta| = 4.0$



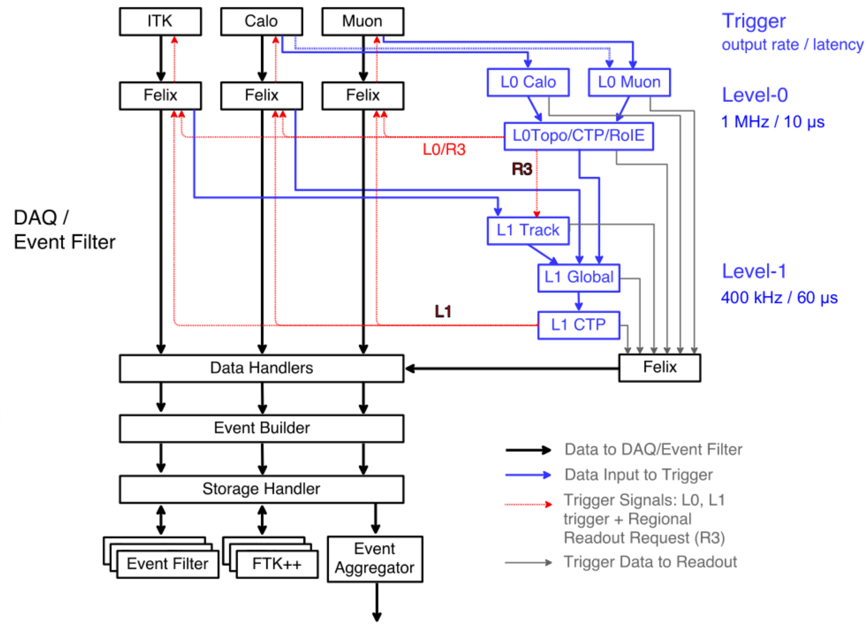
ATLAS HL-LHC Upgrades (3)

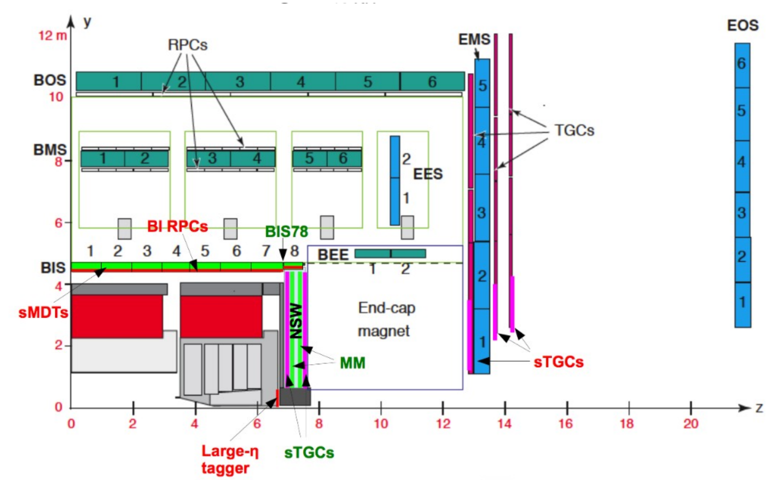
- DAQ & Data Handling (not NSF scope)
  - upgrades to handle larger data volume/rate
    - Data Acquisition (DAQ) & Event Filter (EF)
    - Increases:
      - L1 rate: x4
      - Raw data size: x2.5
  - data distribution electronics for trigger system



ATLAS HL-LHC Upgrades (4)

- Enabling Triggering at the HL-LHC (U.S. NSF focus)
  - new readout electronics in LAr & Tile Calorim's
    - all data off-detector at 40 MHz bunch-crossing frequency
    - more sophisticated algo's at L1
  - new readout electronics in all Muon sub-system
    - all data off-detector at 1 MHz
  - addition of MDT info to L0
    - sharper turnon curves
  - new trigger architecture
    - split L0/L1
    - silicon tracking at L1 (L1Track) & EF (FTK++)
    - combine fine-grained Calo info with Track and Muon (L1Global)
  - muon geometrical acceptance
    - new BI RPCs & sMDTs
    - efficiency: 65% → 95%





ATLAS HL-LHC – US Scope

- Proposed US Scope matches unique US expertise
  - builds on experience in original ATLAS construction & Phase-I
  - ongoing R&D aimed at these scope items
- Two categories of scope
  - "Baseline" Scope: fits within DOE and NSF funding guidance
    - prioritized to identify "Scope Contingency": scope to be dropped if total budget over-runs are anticipated
  - "Opportunity" Scope: additional scope matching US expertise
    - could be added if funds become available (contingency reduction,...)
- WBS Structure (6.x.y.z) designed to streamline reporting
  - Level-2 (x): System
  - Level-3 (y): Institute
  - Level-4 (z): Deliverable (each deliverable may contain separate Items)
- Clear split between DOE and NSF scope at Deliverable Level (along thematic lines)
  - DOE: *Tracking and Data-Handling*
  - NSF: *Enabling Triggering at the HL-LHC*

US Scope - DOE

WBS		Deliverable	Funding	Institutes	US Expertise
6.1	**Pixels**			**Philippe Grenier (SLAC)**	
	6.1.y.1	Pixels Integration	DOE	LBNL	Pixels in original detector & IBL
	6.1.y.2	Pixel Mechanics	DOE	LBNL, Washington	
	6.1.y.3	Pixels Services	DOE	OSU, SLAC	
	6.1.y.4	Local Supports	DOE	ANL, LBNL, SLAC, UCSC, UNM	
	6.1.y.5	Pixels Modules	DOE	ANL, LBNL, OKU, UCSC, UNM, Wash, Wisc	
	6.1.y.6	Off-Detector Electronics	DOE	OKS	
	6.1.y.7	Support	DOE	ANL, SB, SLAC, UNM, Washington	
6.2	**Strips**			**Carl Haber (LBNL)**	
	6.2.y.1	Stave Cores	DOE	BNL, IowaSt, LBNL, Yale	Strips in original detector
	6.2.y.2	Readout/Control Chips	DOE	BNL, LBNL, Penn, UCSC, Yale	
	6.2.y.3	Modules & Integration	DOE	BNL, Duke, LBNL, Penn, UCSC, TBD	
6.3	**Global Mechanics**			**Eric Anderssen (LBNL)**	
	6.3.y.1	Integration System Test	DOE	Indiana, LBNL, SLAC, UCSC	Mechanics in original detector
	6.3.y.2	Outer Cylinder & Bulkhead	DOE	LBNL	Low-mass support structures
	6.3.y.3	Thermal Barrier	DOE	SLAC	
	6.3.y.4	Pixel Support Tube	DOE	LBNL	
	6.3.y.5	DAQ Interface	DOE	SLAC, Washington	
6.4	**Liquid Argon**			**John Parsons (Columbia)**	
	6.4.y.4	System Integration	DOE	BNL	Similar syst. int. tests for original detector
	6.4.y.5	PA/Shaper	DOE	BNL, Penn	FE ASICs for original detector & Phase-I
6.7	**DAQ/Data Handling**			**Jinlong Zhang (ANL)**	
	6.7.y.1	L1Global Aggregator	DOE	BNL	Phase-I gFEX
	6.7.y.2	L1Track/FTK++ Data	DOE	ANL, SLAC	Phase-0/1 FTK
	6.7.y.3	DAQ/FELIX	DOE	ANL, BNL	Phase-I FELIX
	6.7.y.4	RoID	DOE	ANL	Phase-I gFEX

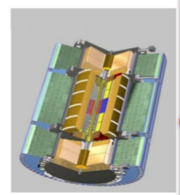
US Scope - NSF

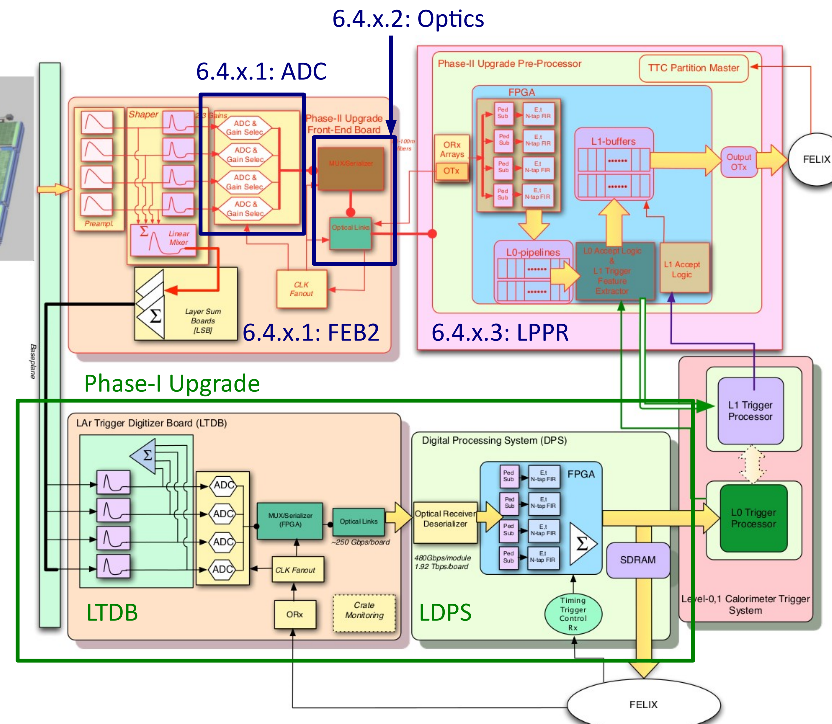
WBS		Deliverable	Funding	Institutes	US Expertise
6.4	**Liquid Argon**			**John Parsons (Columbia)**	
	6.4.y.1	Front End Electronics	NSF	Columbia, UTAustin	FE ASICs and FEB in orig detector & Phase-I
	6.4.y.2	Optics	NSF	SMU	Optics in original detector & Phase-I
	6.4.y.3	Back End Electronics	NSF	Arizona, SB	Phase-I LAr Digital Processing System
6.5	**Tile Calorimeter**			**Mark Oreglia (Chicago)**	
	6.5.y.1	Main Board	NSF	Chicago	MB in original detector
	6.5.y.2	Pre-Processor Interface	NSF	UTArlington	involvement in original sROD
	6.5.y.3	ELMB++ Motherboard	NSF	MSU	Tile DCS in original detector
	6.5.y.4	Low Voltage Power Supply	NSF	NIU, UTArlingron	Tile LVPS in Phase-0
6.6	**Muon**			**Tom Schwarz (Michigan)**	
	6.6.y.1	PCB for Mezzanine	NSF	Arizona	FrontEnd Board for Phase-I NSW
	6.6.y.2	TDC	NSF	Michigan	extensive ASIC design experience
	6.6.y.3	CSM	NSF	Michigan	original detector
	6.6.y.4	Hit Extraction Board	NSF	Illinois	MDT and Muon Phase-I experience
	6.6.y.5	sMDT Chambers	NSF	Michigan, MSU	MDT production in original detector
6.8	**Trigger**			**Elliot Lipeles (Penn)**	
	6.8.y.1	L0Calo	NSF	MSU	built Phase-I system
	6.8.y.2	L0Muon	NSF	Irvine	extensive design experience at Irvine
	6.8.y.3	L1Global	NSF	Chicago, Indiana, LSU, MSU, Oregon, Pitt	Phase-I gFEX
	6.8.y.4	L1Track/FTK++ Processing	NSF	Indiana, Penn, Chicago, Illinois, NIU, Stanford	Phase-0/I FTK

- NSF Scope based on extensive past experience in the U.S.
  - 16 Deliverables, 18 Institutes
- Well defined projects for which the NSF has sole intellectual leadership
  - correspond to clear areas in ATLAS HL-LHC upgrade – see backup slides for details

Liquid Argon Calorimeter (NSF)

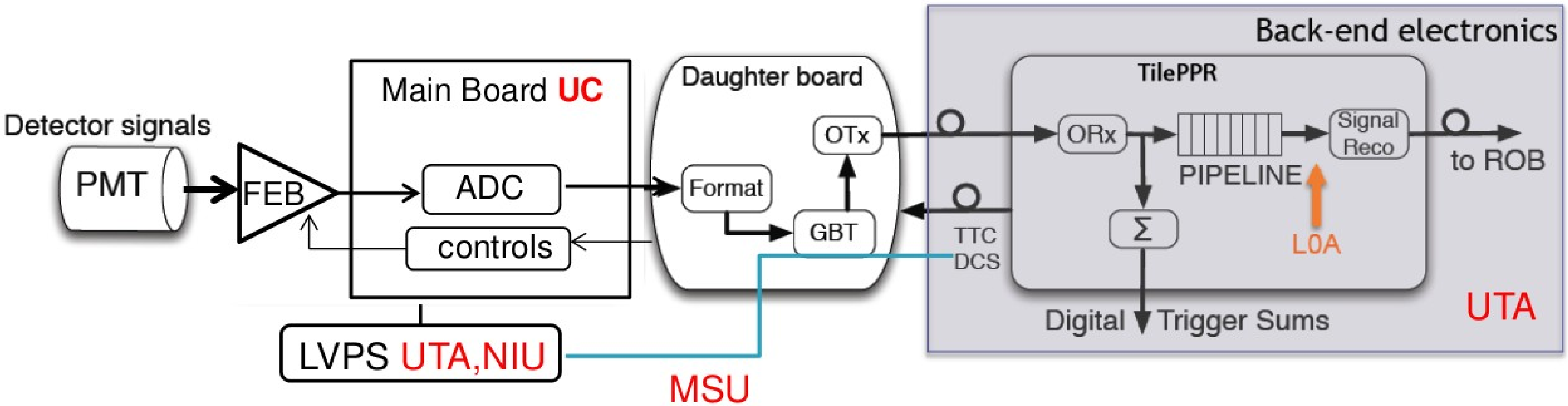
- Replacement of Readout Electronics
  - full-granularity readout at 40 MHz beam crossing rate
- NSF Scope
  - 6.4.x.1: Front End Electronics
    - rad tolerant 40 MHz ADC
    - Front-End Board (FEB2)
    - (PreAmp/Shaper is a DOE deliv)
  - 6.4.x.2: Optics
    - 10 Gbps serializer ASIC
    - VCSEL array driver
    - Optical Tx board (OTx)
  - 6.4.x.3: Back End Electronics
    - LAr Pre-Processor Motherboard (LPPR)
      - hardware & firmware





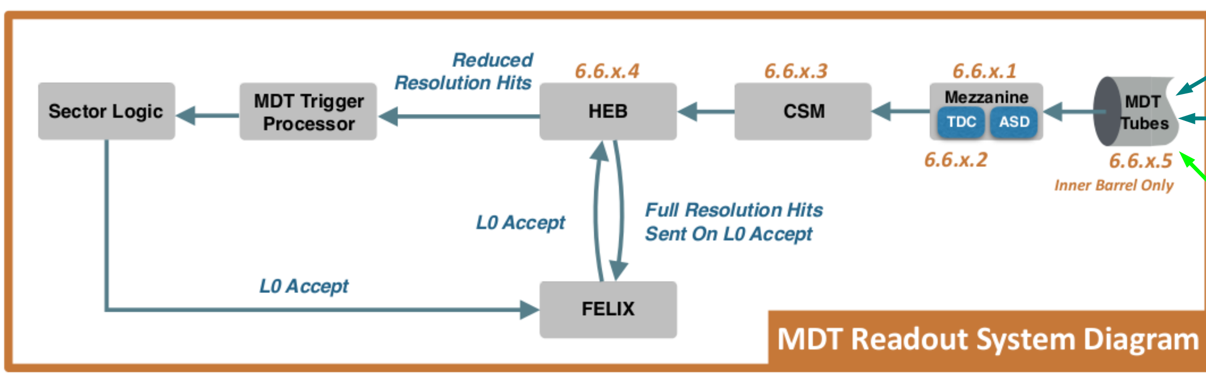
Tile Calorimeter (NSF)

- Replacement of Readout Electronics
  - readout at 40 MHz beam crossing rate
- NSF Scope
  - 6.5.x.1: Main Board (interface between FE ampl/shaper & fast communications DB)
    - R&D on FEB alternatives (3in1 & QIE) – to be produced by France
  - 6.5.x.2: Pre-Processor (PPR) – TDAQi interface board (data to DAQ, trigger)
  - 6.5.x.3: ELMB++ Motherboard (monitoring/control of LVPS, temperature,...)
  - 6.5.x.4: Low Voltage Power Supply (LVPS)

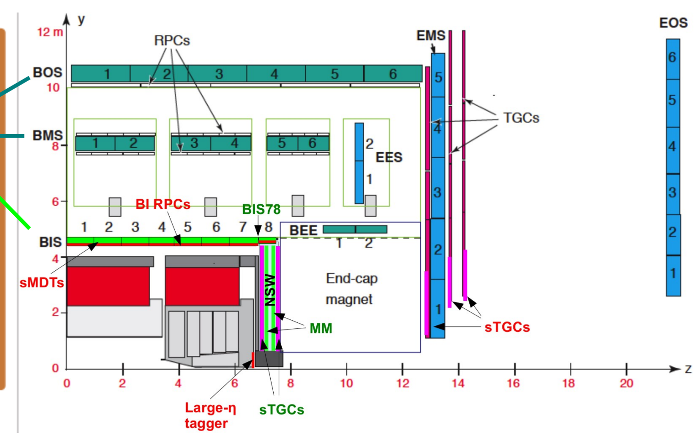


Muon Spectrometer (NSF)

- Replacement of Readout Electronics + Some New Detectors
  - compatibility with new trigger system & enhanced performance
- NSF Scope
  - 6.6.x.1: Mezzanine Card PCB – houses Ampl/Shaper/Discrim & TDC
  - 6.6.x.2: TDC – leading & trailing edges of (s)MDT signals
  - 6.6.x.3: Chamber Service Module (CSM) – data buffering/reformatting
  - 6.6.x.4: Hit Extraction Board (HEB) – data to trigger and DAQ
  - 6.6.x.5: sMDT – new small MDTs chambers in inner barrel region

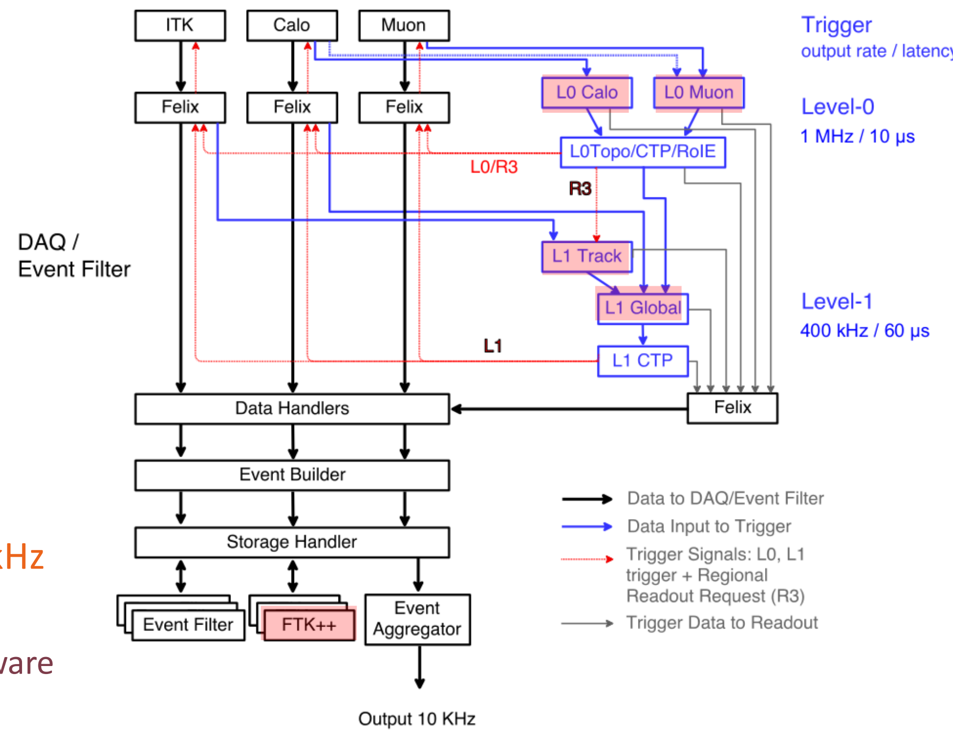


MDT Readout System Diagram



Trigger System (NSF)

- New Architecture to retain Run-1 level efficiencies
- NSF Scope
  - 6.8.x.1: L0Calo
    - optical fiber re-mapping system
  - 6.8.x.2: L0Muon
    - trigger processing mezzanine
  - 6.8.x.3: L1Global
    - 4 firmware algorithms
      - focus on hadronic triggers
  - 6.8.x.4: L1Track/FTK++
    - L1Track: regional tracking at 1 MHz
    - FTK++: full detector tracking at 100 kHz
      - for use in Event Filter
      - likely to use similar or identical hardware to L1Track
    - Mainboards – data preparation/distribution
    - Track Fitting Mezzanines



Physics → NSF Scope Flowdown

SCIENCE GOALS	SCIENCE REQUIREMENTS	NSF SCOPE
$H \to 4\mu$ (2.2%) VBF $H \to ZZ^*, WW^*$ (17%,14%) VBS ssWW (5.9%) SUSY $\chi_1^\pm \chi_2^0 \to \ell bb+X$ (850 GeV)	Muon Trigger • single μ p_T threshold ~ 20 GeV • geometric accept: 95% (barrel)	• Muon Electronics • Tile Electronics • sMDT • L0Muon
VBF $H \to ZZ^*, WW^*$ (17%,14%) VBS ssWW (5.9%) SUSY $\chi_1^\pm \chi_2^0 \to \ell bb+X$ (850 GeV)	Electron Trigger • single e p_T threshold ~ 22 GeV	• LAr+Tile Electronics • L1Global • L1Track/FTK++
$HH \to 4b$ (4.4σ KK Graviton)	Jet Triggers • 4-jet E_T threshold ~ 75 GeV • "fat" jet threshold ~ 375 GeV • jet-vertex confirmation at L1	• Lar+Tile Electronics • L1Global • L1Track/FTK++
Compressed SUSY ($\chi_1^\pm \chi_2^0$)	Missing E_T Trigger • ME_T threshold ~ 200 GeV • track-based ME_T correction	• Lar+Tile Electronics • L1Global • L1Track/FTK++

Cost-Effective Trigger System that meets Science Requirements:

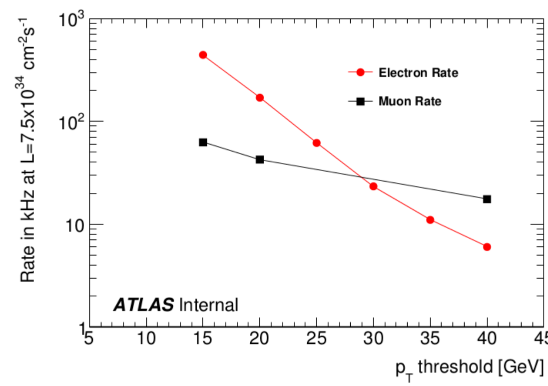
- <L0 accept>=1 MHz (6/10μs); <L1 accept>=400 kHz (30/60μs); <to storage>=10 kHz

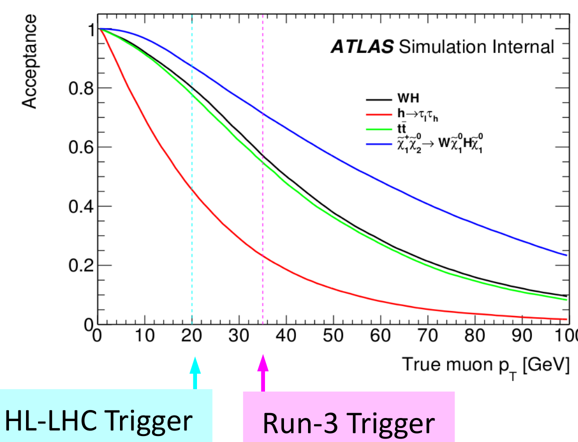
Single Lepton Triggers (1)

- Example: VBF H → WW* or VBS ssWW, where one W →eν, μν
  - single lepton triggers preferred over multi-object triggers: ℓℓ, ℓ+jets,...
    - access to wider range of states, less sensitive to pileup,...

Item	Offline p_T threshold [GeV]	Offline |η|	Efficiency	L0 Rate [kHz]	L1 Rate [kHz]	EF Rate [kHz]
Isolated Single *e*	22	<2.5	95%	200	40	2.20
Forward *e*	35	2.5-4.0	90%	40	8	0.23
Single μ	20	<2.4	95%	40	40	2.20

Lepton Trigger Thresholds



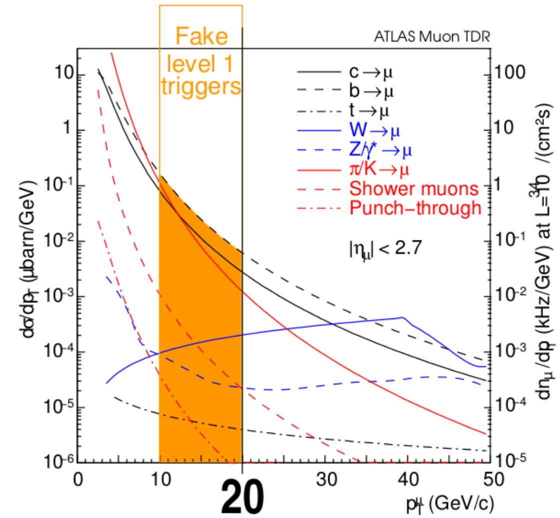


- Use pre-HL-LHC Single Electron Trigger ? - NO
  - raise threshold to 35 GeV to meet rate limit
    - ==> >25% loss in efficiency
- HL-LHC Single Electron Trigger: p_T ~ 20 GeV (L1)
  - x5 rate reduction at L1 w/ 95% efficiency
  - ==> offline-like algorithms
    - full granularity calo data to L1Global
    - track-based isolation w/ L1Track

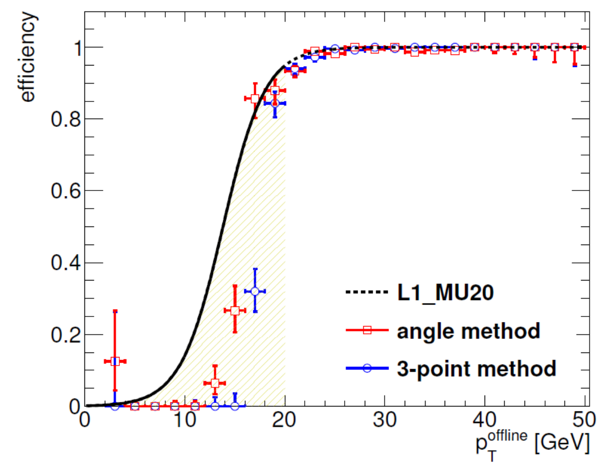
Single Lepton Triggers (2)

- Example: VBF H → WW* or VBS ssWW, where one W →eν, μν

Item	Offline p_T threshold [GeV]	Offline $\|\eta\|$	Efficiency	L0 Rate [kHz]	L1 Rate [kHz]	EF Rate [kHz]
Isolated Single *e*	22	<2.5	95%	200	40	2.20
Forward *e*	35	2.5-4.0	90%	40	8	0.23
Single μ	20	<2.4	95%	40	40	2.20



- Use pre-HL-LHC Single Muon Trigger ? - NO
  - raise threshold to 35 GeV (-25%) to meet rate limit
  - low barrel acceptance: (-30%)
    - ==> total: 45% loss in efficiency (barrel)
- HL-LHC Single Muon Trigger: p_T ~ 20 GeV (L0)
  - ==> add precision MDT info at L1
    - deal with high background at low p_T
  - ==> add sMDT/RPC chambers in inner layer
    - fix poor acceptance in the barrel from holes in coverage + reduced voltage

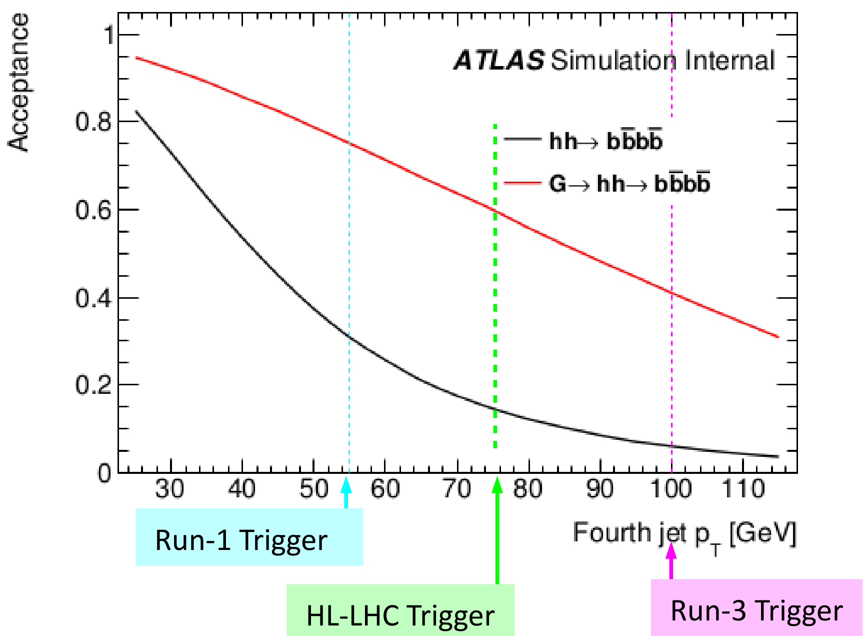


Jet Triggers

- Example: SM hh→4b or KK Graviton→hh→4b
  - single-jet with structure or multi-jet triggers
- Use pre-HL-LHC 4-Jet Trigger ? - NO
  - raise threshold to 100 GeV to meet rate limit
    - ==> x2 loss in eff (SM hh)
    - ==> 50% loss in eff (KK Grav)
- HL-LHC 4-Jet Trigger: p_T ~ 75 GeV
  - ==> Jet-Vertex association
    - pileup suppression critical for multi-object triggers (L1Track)

More examples of Science → Scope Flowdown in L2 Talks

4th Jet Trigger Thresholds



Research & Development

- HL-LHC R&D ongoing for several years already
  - ==> quite well-defined ATLAS HL-LHC detector
- ATLAS R&D program ==> technical decisions + prep for TDRs

System	TDR	Technical Decision (Date)
Liquid Argon	Q3 2017	• FE chip (PA/Shaper: BNL vs French) – TDR
TileCal	Q4 2017	• FE chip (3-in-1, QIE, FATALIC) – Sep. 2017
Muon	Q2 2017	• replace inner chambers (sMDT/RPC) – spring 2016 • TDC technology (ASIC, FPGA, VMM-like) – TDR • accessibility of inner chambers – TDR
Trigger & DAQ	Q4 2017	• architecture (L0/L1 vs L0-only) – Summer 2016

- Robust R&D program in US (details in breakout sessions)
  - LAr: custom ASICs (65nm PA/Shaper, ADC, Serializer), sFCAL studies
  - TileCal: drawer demonstrator in testbeams and ATLAS
  - Muon: demonstrator electronics (TDC, CCM, HEB), sMDT tube/chamber site setup
  - Trigger: ongoing Phase-I program, L1Track demonstrator

Risk & Contingency

- External Dependencies: non-NSF items that impact NSF Deliverables
  - NSF Deliverables chosen to be as self-contained as possible
  - clear boundaries/interfaces to non-NSF items
- Budget Contingency: funds set aside to cover possible cost over-runs
  - (1) from deliverable risk analysis & (2) at global level (cross-system)
    - currently estimated top-down for each L2 system
  - moving to bottom-up estimate based on Item-level risks
    - using "standard" contingency rules (docDB #75) as used also for Phase-I project
- Schedule Contingency: slack in schedule (float in Timeline charts)
  - float = time between end of production and "required at CERN"
    - note: required at CERN dates are evolving as ATLAS plans evolve
  - see L2 talks for details
- Scope Contingency: essentially a prioritization
  - what elements of the project could be dropped if we anticipate over-running our total budget (base + budget contingency)
    - timing of when scope contingency can be realized is cruci al
- See also Risk Management Plan (docDB #4) & Risk Registries (docDB #72,77)

System Engineering

- System Engineering "focuses on how to design and manage complex engineering systems over their life cycles" (Wikipedia)
  - crucial tool in managing risks in a large, complex project like ATLAS
  - concentrate on clearly defined requirements, interfaces, and external dependencies
- Incorporated into all levels of ATLAS HL-LHC upgrade
  - U.S. ATLAS System Integrators
    - one for each U.S. ATLAS L2 system
      - LAr: H.Chen (BNL), Tile: G.Drake (ANL/Chicago), Muon: D.Levine (Michigan), Trigger: B.Kunkler (Indiana)
    - ensure compliance with ATLAS requirements and compatibility with other items
  - U.S. ATLAS System Integration Engineer
    - one for all of U.S. ATLAS: tbd
    - main point of contact between U.S. ATLAS and ATLAS on system engineering issues
      - interface with: U.S. ATLAS System Integrators, U.S. ATLAS Management Team (esp. Technical Coordinator), ATLAS Upgrade Project Leaders, ATLAS Technical Coordination
  - ATLAS Technical Coordination (TC) Team
    - fills many System Engineering roles. Mandate from original ATLAS TC TDR:
      - "The Technical Co-ordinator monitors the technical aspects of the construction of the detector (sub-)systems, is responsible for the overall detector integration, for the overall construction of the detector and of the experimental area and for common project issues"

Main External Dependencies

WBS	Title	Item	External Dependency	Mitigation Strategy
6.4	**Liquid Argon**			
6.4.x.1	FE Electronics	Frontend Board (FEB2)	PA/shaper ASIC (BNL/UPenn - DOE scope)	Maintain tight coordination and oversight via System Engineering. Well-advanced SiGe version is a backup in case of problems with development of baseline in 65 nm CMOS. Complementary efforts underway in France.
6.4.x.2	Optics		Project is self-contained in NSF scope	
6.4.x.3	BE Electronics	LPPR Motherboard (MB)	Mezzanine card (France)	Clearly define, with help from System Engineering, interfaces between MB and mezzanines. Develop mezzanine-style test cards that will allow MB to be fully tested and qualified even without final mezzanines being available.
6.5	**Tile Calorimeter**			
6.5.x.1	Main Board	Testing	Front-End cards (France)	can use cards from the Demonstrator
6.5.x.2	Preprocessor	TDAQi blades	PPR front-end (tbd)	can use prototype PPR for testing production TDAQi
6.5.x.3	ELMB++	ELMB motherboard	ELMB++ mezzanine (ATLAS)	use prototypes to test production Motherboard
6.5.x.4	LVPS		project is self-contained	n/a
6.6	**Muon**			
6.6.x.1	Mezzanine Card		ASD (Germany)	ASD scheduled to be completed two years before needed for Mezz. and TDC
6.6.x.2	TDC		ASD (Germany)	same as above
6.6.x.3	CSM		project is self-contained to NSF	
6.6.x.4	HEB		project is self-contained to NSF	
6.6.x.5	sMDT		project is self-contained to NSF	
6.8	**Trigger**			
6.8.x.1	L0Calo	FOX	Tile fiber mapping (ATLAS)	Tile & Trigger/DAQ System Engineers
6.8.x.2	L0Muon		Carrier card not ready for testing	Develop stand-alone testing
6.8.x.3	L1Global	Algorithm FW	L1Global Aggregator Board (DOE) L1Global Proccesor Board (UK)	Firmware development can proceed on commercial test cards or prototypes
6.8.x.4	L1Track/FTK++		Rear Transition Module = RTM (DoE), 1st Stage Mezzanine (UK)	2nd stage mezzanine testing only is probably sufficient, mainboard preproduction can be tested with RTM prototype allowing a late RTM

docDB #138

Main Technical Risks

- Bottom-up assessment of technical risk being developed
  - Technical Risk Registry: docDB #77
  - aim for cost, schedule, scope risk at item level
  - Largest risks identified: informed top-down contingency
    - this will feed into bottom-up contingency estimate
- Main risks per system
  - LAr: cost and schedule risks in ASIC development
    - mitigation: early engineering effort, use common 65nm CMOS process (easier to find partners to share NRE costs)
  - Tile: schedule risk because installation is early in shutdown
    - mitigation: 12-19 months of schedule float
  - Muon: customized CSMs may be required for legacy electronics
    - mitigation: early decision on need for legacy electronics (May 2016)
  - Trigger: specifications for L0Muon at an early stage – design may change
    - mitigation: system engineering oversight

Schedule Contingency (Float)

- Working definition of Schedule Float
  - difference between the time of the last production of a deliverable and the earliest time that deliverable is needed at CERN in order for ATLAS to stay on schedule for the start of Run-4

NSF Deliverables Schedule Float to Installation

	WBS	Title	Acceptance Test Complete (Mo/Yr)	CERN Required Date (Mo/Yr)	Minimum Float to CERN required date (months)
	6.4.x.1	FE Electronics	Dec-23	Jan-25	12
Liquid Argon	6.4.x.2	Optics	Mar-23	Dec-22	6
	6.4.x.3	BE Electronics	Mar-24	Oct-24	6
	6.5.x.1	Main Board	Dec-22	Oct-23	9
Tile Calorimeter	6.5.x.2	Pre-Processor	Jun-23	Apr-24	9
	6.5.x.3	ELMB**Motherboards	Dec-22	Oct-23	9
	6.5.x.4	Low Voltage Power System	Dec-22	Oct-23	9
	6.6.x.1	Mezzanine	Jun-23	Apr-24	9
	6.6.x.2	TDC	Dec-22	Apr-24	15
Muon	6.6.x.3	CSM	Mar-23	Apr-24	12
	6.6.x.4	Hit Extraction Board	Mar-24	Jan-25	9
	6.6.x.5	sMDT Chambers	Jun-22	Apr-23	9
	6.8.x.1	L0Calo	Sep-23	Dec-24	14
Trigger	6.8.x.2	MDT Trigger	Mar-24	Dec-24	8
	6.8.x.3	L1 Global Processing	Sep-23	Dec-24	14
	6.8.x.4	L1 Track/FTK++ Processing	Mar-24	Dec-24	8

see schedules
in docDB
for more details

Scope Contingency

- Dropping U.S. scope could have serious consequences
  - all elements of HL-LHC upgrade needed to achieve Science Goals
- Strategies in defining scope contingency
  - items that could be "staged" ==> possible to recover performance
  - items that could most easily be transferred to a non-U.S. partner
    - e.g. production (full or partial), some firmware modules
    - would require negotiation with ATLAS

System	Scope Contingency	Savings
6.4 Liquid Argon	less firmware for BE produce less FEB2/Otx/BE boards	\$1M \$1M
6.5 TileCal	drop LV box assembly	\$0.4M
6.6 Muon	drop production of TDC	\$1.2M
6.8 Trigger	drop one L1Global Algorithm produce less L1Track/FTK++ MBs	\$0.4M \$1.1M

Scope Opportunity

- As project becomes better defined
  - budget contingency decreases
  - adjustments to US scope may also occur
- Each L2 system maintains a list of additional scope that could be added should funds become available
  - decisions need to be made at time of system TDRs (responsibilities defined)
  - maintain some level of US R&D in these Opportunity areas in case they are realized

System	Scope Opportunity	Cost	Benefit/Motivation
6.4 Liquid Argon	• sFCAL • HGTD	\$5.4M \$5.3M	US-led effort significant US leadership
6.5 TileCal	• produce all LVPS (cf 50%)	\$1.1M	reduce external dependency
6.8 Trigger	• add 1 L1Global Algo	\$0.4M	US expertise here

Conclusions

- Strong motivation for ATLAS HL-LHC upgrade
  - HL-LHC ==> physics opportunities & technical challenges for ATLAS
- Clear US scope proposal that meets funding guidance
  - result of extensive discussion with ATLAS – finalize on TDR timescales
  - builds on unique US expertise and experience
  - NSF scope: Enabling Triggering at the HL-LHC
    - DOE scope: Tracking and Data Handling
- Extensive R&D program in the US
  - aimed at preparing for construction of US scope
  - provide input to short-term technical decisions and TDRs
- Active Risk Management
  - input from sub-system experts, L2 managers System Engineers
  - ==> contingencies to ensure on-time completion within budget

BACKUP

Main LHC Machine Changes

- Phase-I Upgrades
  - injector upgrade, pt.4 cryogenics, dispersion suppression dipoles, collimators
- HL-LHC (Phase-II) Upgrades
  - Goals: 300 fb^{-1} per year ==> $L_{peak} = 7.5 \times 10^{34}\ cm^{-2}\ s^{-1}$
    - luminosity leveling to reduce pileup in experiments
  - Inner Triplet Magnets (final focusing): failures at 300 fb^{-1}
    - new Nb_3Sn technology allows large-aperture fields >9T
  - Crab-Crossing Cavities: compensate for large crossing angle
  - Cryogenics: full separation between SCRF and Magnet cooling
  - Collimation: lower impedance, new configuration
  - Power Converters: rad hard electronics or displace out of rad zone
  - Quench Protection, Machine Protection, Remote Manipulation

HL-LHC Machine Parameters

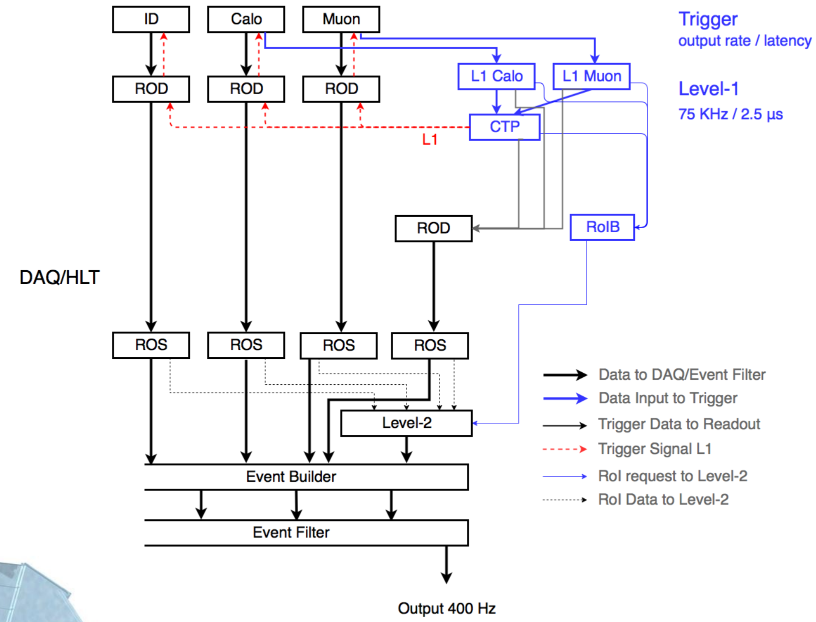
Parameter	Nominal LHC (design report)	HL-LHC (standard)	HL-LHC (BCMS)
Beam energy in collision [TeV]	7	7	7
Particles per bunch, N [10^{11}]	1.15	2.2	2.2
Number of bunches per beam	2808	2748	2604
Number of collisions in IP1 and IP5[1]	2808	2736	2592
N_{tot} [10^{14}]	3.2	6.0	5.7
Beam current [A]	0.58	1.09	1.03
Crossing angle in IP1 and IP5 [μrad]	285	590	590
Normalized long range beam-beam separation [σ]	9.4	12.5	12.5
Minimum β^* [m]	0.55	0.15	0.15
ε_n [μm]	3.75	2.50	2.50
ε_L [eVs]	2.50	2.50	2.50
r.m.s. energy spread [0.0001]	1.13	1.13	1.13
r.m.s. bunch length [cm]	7.55	7.55	7.55
IBS horizontal [h]	105	18.5	18.5
IBS longitudinal [h]	63	20.4	20.4
Piwinski parameter	0.65	3.14	3.14
Total loss factor R_0 without crab-cavity	0.836	0.305	0.305
Total loss factor R_1 with crab-cavity	-	0.829	0.829
Beam-beam / IP without crab cavity	0.0031	0.0033	0.0033
Beam-beam / IP with crab cavity	0.0038	0.011	0.011
Peak luminosity without crab-cavity [10^{34} cm^{-2}s^{-1}]	1.00	7.18	6.80
Virtual luminosity with crab-cavity $L_{peak}\times R_1/R_0$ [10^{34} cm^{-2}s^{-1}]	(1.18)	19.54	18.52
Events/crossing without levelling and without crab-cavity	27	198	198
Levelled luminosity [10^{34} cm^{-2}s^{-1}]	-	5.00[2]	5.00[2]
Events/crossing (with levelling and crab-cavities for HL-LHC)[3]	27	138	146
Maximum line density of pile up events during fill [event/mm]	0.21	1.25	1.31
Levelling time [h] (assuming no emittance growth)[3]	-	8.3	7.6
Number of collisions in IP2/IP8	2808	2452/2524[4]	2288/2396[4]
N at LHC injection [10^{11}][5]	1.20	2.30	2.30
Maximum number of bunches per injection	288	288	288
N_{tot} / injection [10^{13}]	3.46	6.62	6.62

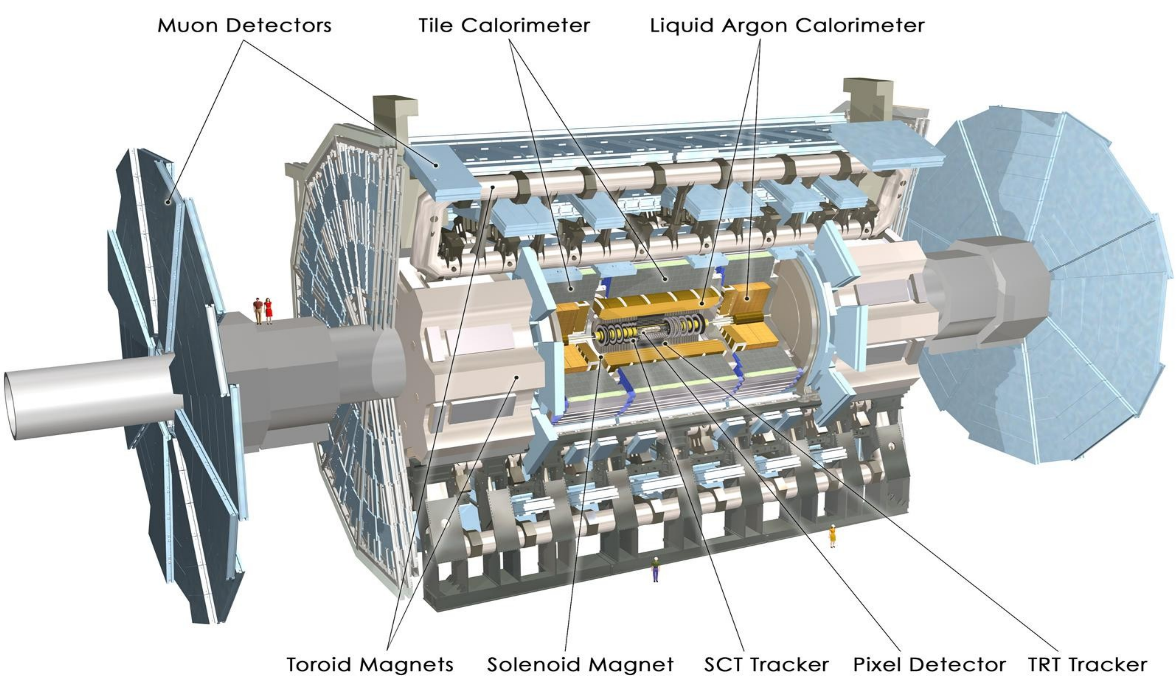
HL-LHC Preliminary Design Report
CERN-ACC-2014-0300
November, 2014

ATLAS Evolution: Run 1

2012 ATLAS Detector

- <u>Inner Detector:</u> Silicon pixels & strips, TRT
- <u>Calorimeters:</u> Liquid Argon, Scint. Tile, FCAL
- <u>Muon:</u> RPC, TGC (trig), MDT, CSC (precision)
- <u>Forward:</u> LUCID, ZDC, ALFA
- <u>Magnets:</u> 2T solenoid (track), toroid (muon)





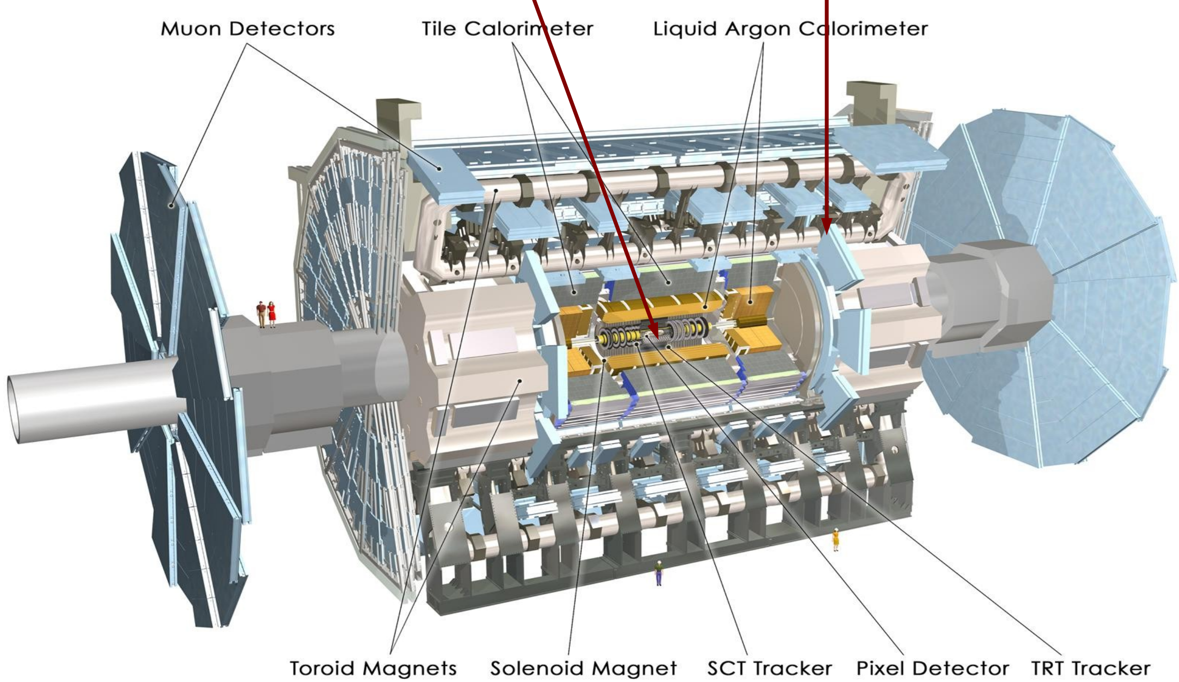
2012 Trigger/DAQ

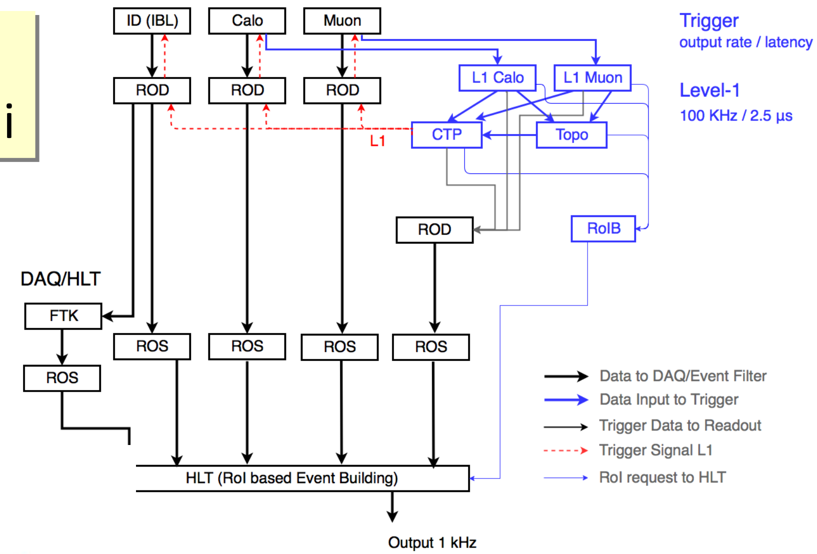
- 3-Level System
  - L1: Calo + Muon
  - L2: RoI-based
  - EF: similar to offline
- Data Acquisition
  - 400 Hz to tape

ATLAS Evolution: Run 2

Phase-0 Upgrades
- effective operations at 1.6 x design lumi

Main Detector Changes
- Inner Detector: inner silicon layer (IBL)
- Muons: CSC readout, endcap completed
- Forward: all upgraded (+ AFP)



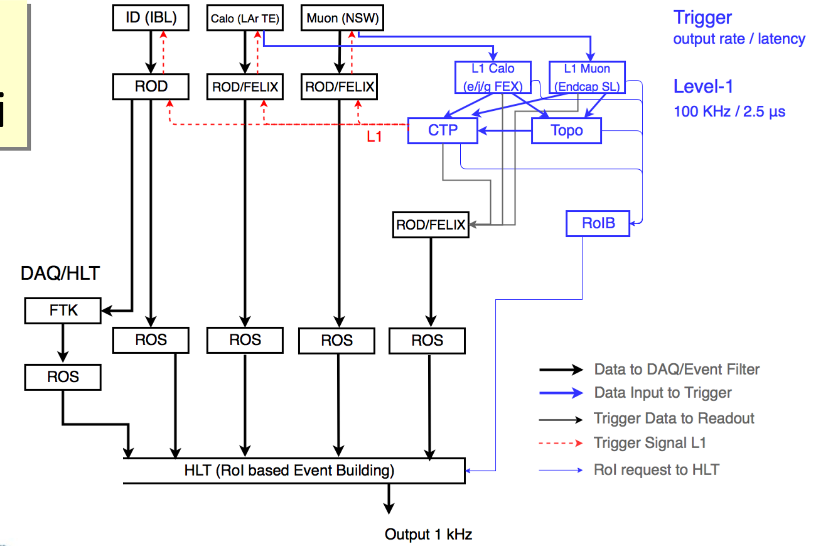


Trigger/DAQ Changes
- L1 Topological Trigger
- Fast Tracker (FTK) → L2
- Merge L2 and EF
- Simplify Dataflow

ATLAS Evolution: Run 3

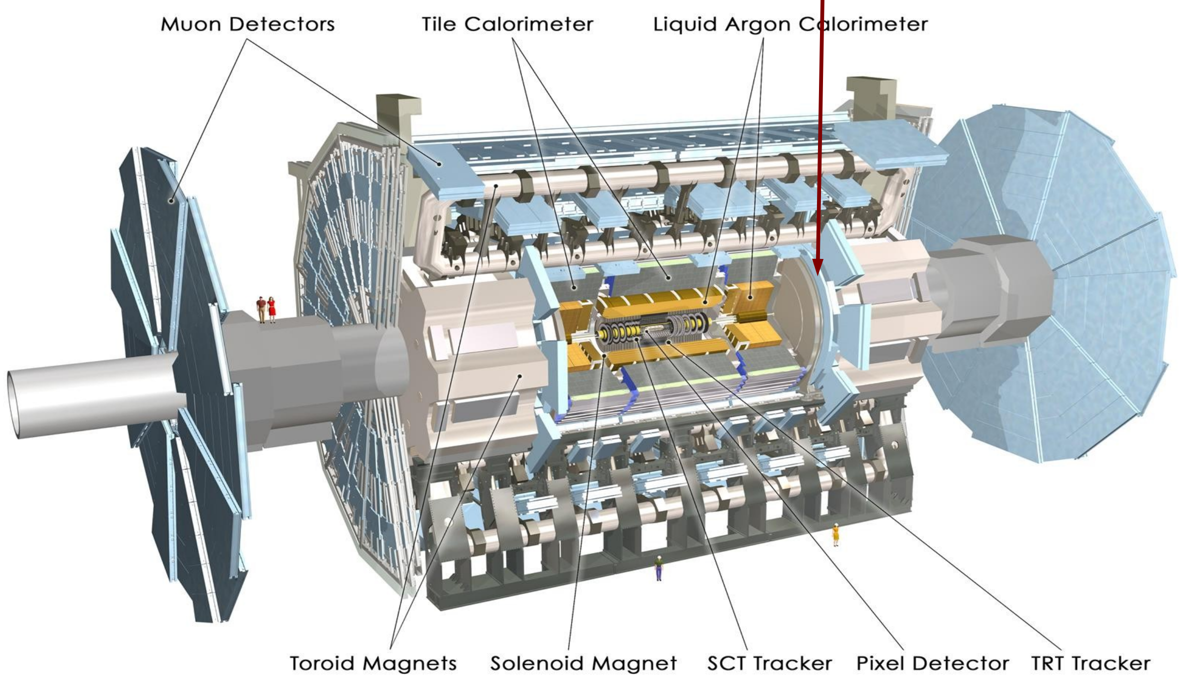
Phase-I Upgrades

- effective operations at 2-3 x design lumi



Main Detector Changes

- Muon: New Small Wheel (NSW)
- Calorimeter: LAr trigger electronics



Trigger/DAQ Changes

- L1Calo Feature Extractors (e/j/gFEX)
- NSW to Muon Trigger
- Topology & Central Trigger
- Complete FTK
- FELIX data distribution

Summary of Scoping Scenarios

- The HL-LHC ATLAS Reference Scenario allows us to meet our Science Requirements and HL-LHC Physics Goals
  - Have studied sensitivity to meeting these requirements by considering two less ambitious scenarios (details in Scoping Document)
- Main differences
  - reduce tracking & trigger coverage from $|\eta| < 4.0 \rightarrow 3.2 \rightarrow 2.7$
  - reduce maximum allowed trigger rates and increase L1Track thresholds
  - reduce muon system trigger coverage

ATLAS Scoping Scenarios: ITK & Calo

Detector System	Scoping Scenarios Reference (275 MCHF)	Middle (235 MCHF)	Low (200 MCHF)
Inner Tracker			
Pixel Detector	$\lvert\eta\rvert \leq 4.0$	$\lvert\eta\rvert \leq 3.2$	$\lvert\eta\rvert \leq 2.7$
Barrel Strip Detector	✓	✓ [No stub layer]	✓ [No stereo in layers #2,#4] [Remove layer #3] [No stub layer]
Endcap Strip Detector	✓	✓ [Remove 1 disk/side]	✓ [Remove 1 disk/side]
Calorimeters			
LAr Calorimeter Electronics	✓	✓	✓
Tile Calorimeter Electronics	✓	✓	✓
Forward Calorimeter	✓	✗	✗
High Granularity Precision Timing Detector	✓	✗	✗

ATLAS Scoping Scenarios: Muon

Muon Spectrometer	Scoping Scenarios Reference (275 MCHF)	Middle (235 MCHF)	Low (200 MCHF)
Barrel Detectors and Electronics			
RPC Trigger Electronics	✓	✓	✓
MDT Front-End and readout electronics (BI+BM+BO)	✓	✓ [BM+BO only]	✓ [BM+BO only]
RPC Inner layer in the whole layer	✓	✓ [in half layer only]	✗
Barrel Inner sMDT Detectors in the whole layer	✓	✓ [in half layer only]	✗
MDT L0 Trigger Electronics (BI +BM+BO)	✓	✓ [BI +BM only]	✓ [BI +BM only]
End-cap and Forward Muon Detectors and Electronics			
TGC Trigger Electronics	✓	✓	✓
MDT L0 Trigger and Front-End read-out electronics (EE+EM+EO)	✓	✓ [EE +EM only]	✓ [EE +EM only]
sTGC Detectors in Big Wheel Inner Ring	✓	✓	✓
Very-forward Muon tagger	✓	✗	✗

ATLAS Scoping Scenarios: TDAQ

Trigger and Data Acquisition	Scoping Scenarios Reference (275 MCHF)	Middle (235 MCHF)	Low (200 MCHF)
Level-0 Trigger System			
Central Trigger	✓	✓	✓
Calorimeter Trigger (e/γ)	$\lvert\eta\rvert < 4.0$	$\lvert\eta\rvert < 3.2$	$\lvert\eta\rvert < 2.5$
Muon Barrel Trigger	MDT everywhere RPC-BI Tile-μ	MDT (BM & BO only) Partial η coverage RPC-BI Tile-μ	MDT (BM & BO only) No RPC-BI Tile-μ
Muon End-cap Trigger	MDT everywhere	MDT (EE&EM only)	MDT (EE&EM only)
Level-1 Trigger System			
Output Rate [kHz]	400	200	200
Central Trigger	✓	✓	✓
Global Trigger	✓	✓	✓
Level-1 Track Trigger (*RoI based tracking*)	$p_T > 4$ GeV $\lvert\eta\rvert \leq 4.0$	$p_T > 4$ GeV $\lvert\eta\rvert \leq 3.2$	$p_T > 8$ GeV $\lvert\eta\rvert \leq 2.7$
High-Level Trigger			
FTK++ (*Full tracking*)	$p_T > 1$ GeV 100 kHz	$p_T > 1$ GeV 50 kHz	$p_T > 2$ GeV 50 kHz
Event Filter	10 kHz output	5 kHz	5 kHz
DAQ			
Detector Readout	✓ [400 kHz L1 rate]	✓ [200 kHz L1 rate]	✓ [200 kHz L1 rate]
DataFlow	✓ [400 kHz L1 rate]	✓ [200 kHz L1 rate]	✓ [200 kHz L1 rate]

ATLAS CORE Costs: Scoping Doc

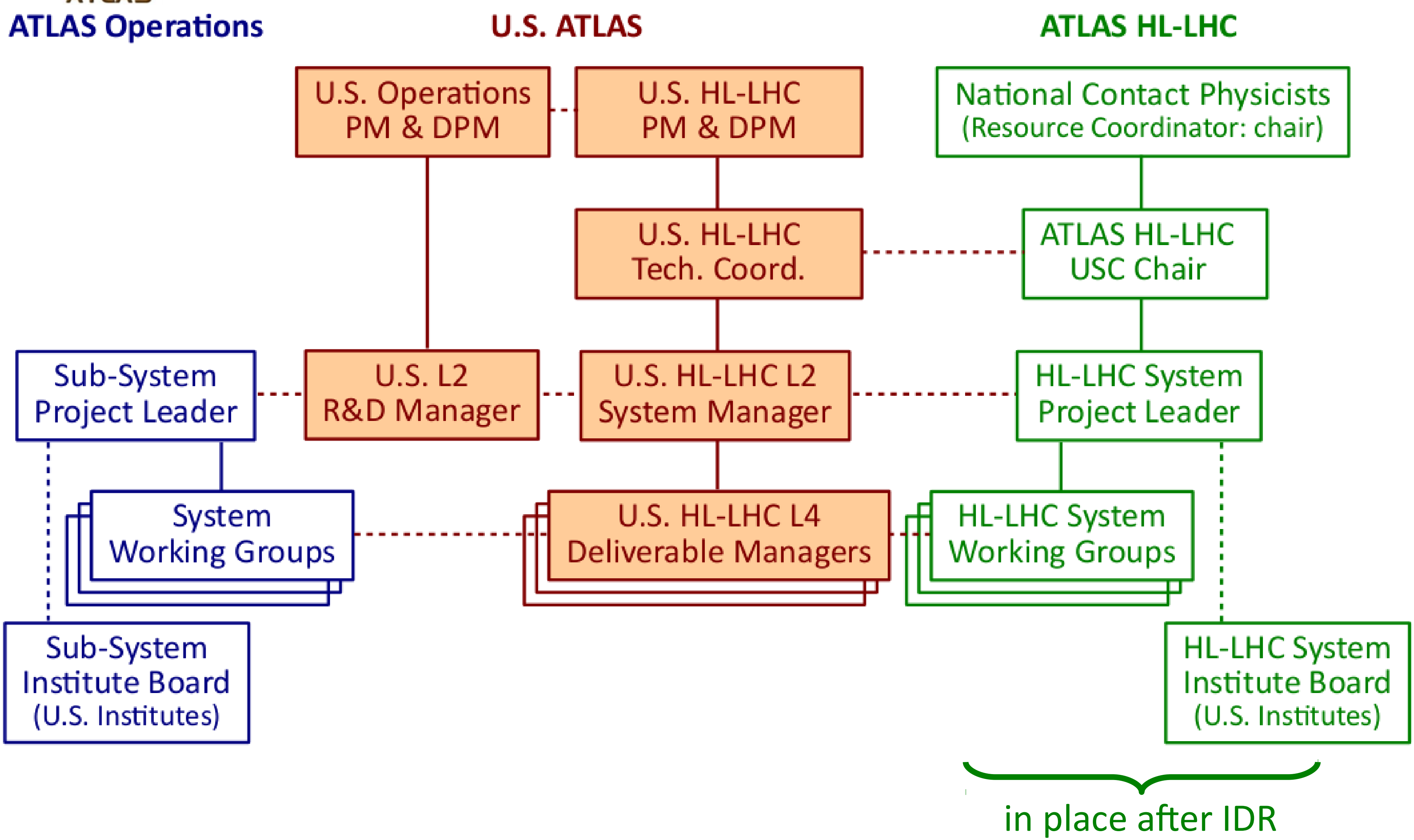
WBS	Detector system	Reference Detector Total Cost [MCHF]	Middle Scenario Differential Cost [MHCF]	Low Scenario Differential Cost [MCHF]
	ATLAS	**271.04**	**-42.55**	**-71.16**
1.	TDAQ	43.31	-11.41	-18.19
1.1	L0 Central Trigger	1.21	-	-
1.2	L0 Calorimeter Trigger	0.70	-	-0.24
1.3	L0 End-cap Muon	2.56	-0.11	-0.11
1.4	L0 Barrel Muon	1.32	-0.14	-0.17
1.5	L1 Central Trigger	1.93	-	-
1.6	L1 Global Trigger	3.39	-	-
1.7	L1 Track	4.19	-0.67	-2.49
1.8	FTK++	13.03	-4.88	-9.56
1.9	DAQ/Event Filter	14.98	-5.62	-5.62
2.	ITk	120.36	-7.2	-23.6
2.1	Pixel	32.19	-0.9	-4.8
2.2	Strip	72.10	-6.3	-18.8
2.3	Common Items	16.08	-	-
3.	LAr	45.98	-13.60	-13.60
3.1	Read-out electronics	31.39	-	-
3.2	sFCal	10.03	-10.03	-10.03
3.3	HGTD	4.56	-4.56	-4.56
3.4	LAr MiniFCal		+0.91	
3.5	Si-based MiniFCal		+3.57	
4.	Tile	8.58	-	-
5.	Muon	34.08	-8.78	-12.79
5.1	MDT	7.69	-2.07	-3.16
5.2	RPC	7.99	-2.32	-4.79
5.3	TGC	4.44	-	-
5.4	High-Eta Tagger	3.50	-3.50	-3.50
5.5	Power System	10.47	-0.89	-1.34
6.	Forward	1.30	-	-
7.	Integration & Installation	17.42	-1.56	-2.98

Object Performance Impacts Physics

Detector system	Trigger–DAQ		Inner Tracker	Inner Tracker + Muon Spectrometer	Inner Tracker + Calorimeter		
	Efficiency/ Thresholds						
Object Performance / Physics Process	μ±	e±	b-tagging	$\mu^{\pm}$ Identification/ Resolution	Pile-up rejection	Jets	$E_{\mathrm{T}}^{\mathrm{miss}}$
$H \longrightarrow 4\mu$	✓			✓			
VBF $H \to ZZ^{(*)} \to \ell\ell\ell\ell$	✓	✓		✓	✓	✓	
VBF $H \to WW^{(*)} \to \ell\nu\ell\nu$	✓	✓	✓	✓	✓	✓	✓
SM VBS ssWW	✓	✓		✓	✓	✓	✓
SUSY, $\chi_1^{\pm}\chi_2^{o} \to \ell b\bar{b} + X$	✓	✓	✓	✓	✓	✓	✓
BSM $HH \to b\bar{b}b\bar{b}$			✓			✓	

√ = object contributes to the analysis of this physics process

Interaction with International ATLAS



US Leadership in ATLAS Upgrade

Sub-System	Name	Institute	Role
Upgrade	Kevin Einsweiller	LBNL	Upgrade Steering Group Coordinator
	Mark Oreglia	Chicago	Member Upgrade Steering Group
ITK	Philippe Grenier	SLAC	Pixel Upgrade Deputy Project Leader
	Maurice Garcia-Sciveres	LBNL	RD-53 Co-Spoksperson
	Alex Grillo	UCSC	ITK Electronics Coordinator
	Abe Seiden	UCSC	Strip TDR editor
LAr	Francesco Lanni	BNL	HGTD Co-Project Leader
	Gustaaf Brooijmans	Columbia	LAr HL-LHC Electronics Co-Convenor
	Stephanie Majewski	Oregon	LAr HL-LHC Simulation Co-Convenor
TileCal	Irene Vichou	UIUC	TileCal Project Leader
	Gary Drake	ANL	TileCal Project Engineer
	Mark Oreglia	Chicago	TileCal Upgrade Co-Leader
	Mark Oreglia	Chicago	Scoping Document editor
Muon	Christoph Amelung	Brandeis	Muon Project Leader
TDAQ	David Strom	Oregon	TDAQ Project Leader
	Chris Bee	Stony Brook	TDAQ Institute Board Chair
	Jinlong Zhang	ANL	FELIX Project Leader
	Elliot Lipeles	Penn	TDAQ IDR editor
	Jinlong Zhang	ANL	TDAQ IDR editor

NSF Scope in ATLAS LAr

NSF FRACTIONS OF HL-LHC LAR CALORIMETER UPGRADE

ATLAS WBS	ATLAS Item (Scoping Doc)	US WBS	Deliverable	NSF Fraction Design	NSF Fraction Production
3	**LAr Calorimeter**	**6.4**	**LAr Calorimeter**		**~ 22%**
3.1	**LAr Readout Electronics**				
3.1.1	**LAr FE Electronics**				**~ 29%**
3.1.1.1	Frontend Boards (FEB2)	6.4.x.1, 6.4.x.2		100%	67%
3.1.1.2	Optical fibres and fibre plant			-	-
3.1.1.3	Frontend power distribution system			-	-
3.1.1.4	HEC LVPS			-	-
3.1.1.5	Calibration system			-	-
3.1.1.6	Shipping and logistics			-	-
3.1.2	**LAr BE Electronics**				**~ 13%**
3.1.2.1	LAr Preprocessor boards (LPPR)				
	LPPR Motherboards	6.4.x.3		100%	67%
	LPPR Mezzanines			-	-
3.1.2.2	Transition modules			-	-
3.1.2.3	ATCA shelves			-	-
3.1.2.4	ATCA switches			-	-
3.1.2.5	Server PC			-	-
3.1.2.6	Controller PC			-	-
3.1.2.7	FELIX/TTC system			-	-

NSF Scope in ATLAS Tile

NSF FRACTIONS OF HL-LHC TILECAL UPGRADE

ATLAS WBS	ATLAS Item (Scoping Doc)	US WBS	Deliverable	NSF Fraction Design	NSF Fraction Production
4	**Tile Calorimeter**	**6.5**	**Tile Calorimeter**		**21%**
4.1	**Drawer Mechanics**				**-**
4.1.1	Mini-drawers				-
4.1.2	Tools/Mechanics				-
4.2	**On-detector Electronics**				**32%**
4.2.1	PMT Dividers				-
4.2.2	FE Boards				-
4.2.3	Main Boards	6.5.x.1	Main Boards	100%	100%
4.2.4	Daughter Boards				-
4.2.5	LVPS System				53%
	ELMB++				-
	ELMB++ Motherboards	6.5.x.3	ELMB++ Motherboards	100%	100%
	LVPS	6.5.x.4	LVPS	100%	50%
4.2.6	HV System				-
4.3	**Off-detector Electronics**				**18%**
4.3.1	TilePPR				-
	TilePPr				-
	Tile TDAQi	6.5.x.2	TDAQi	100%	100%
4.4	**Infrastructure**				**-**
4.4.1	Services				-

NSF Scope in ATLAS Muon

NSF FRACTIONS OF HL-LHC MUON SPECTROMETER UPGRADE

ATLAS WBS	ATLAS Item (Scoping Doc)	US WBS	Deliverable	NSF Fraction Design	NSF Fraction Production
5	**Muon Spectrometer**	**6.6**	**Muon Spectrometer**		**20%**
5.1	**MDT**				**87%**
5.1.1	sMDT detector	6.6.x.5	sMDT Chambers	50%	50%
5.1.2	sMDT installation basket				-
5.1.3	Mezzanine cards				75%
	PCB Board	6.6.x.1	PCB for Mezzanine	100%	100%
	ASD				-
	TDC	6.6.x.2	TDC	100%	100%
5.1.4	CSM cards			100%	100%
	CSM	6.6.x.3	CSM	100%	100%
	Hit Extraction Board	6.6.x.4	Hit Extraction Board	100%	100%
5.2	**RPC**				**-**
5.2.1	Detectors				-
5.2.2	Installation mock-up				-
5.2.3	Installation tooling				-
5.2.4	On-detector electronics				-
5.3	**TGC**				**-**
5.3.1	On-detector electronics				-
5.3.2	sTGC on BW inner ring				-
5.4	**High Eta-Tagger**				**-**
5.4.1	Detector				-
5.4.2	FE electronics				-
5.4.3	Services and infrastructure				-
5.5	**Power System**				**-**
5.5.1	MDT				-
5.5.2	RPC				-
5.5.3	TGC				-

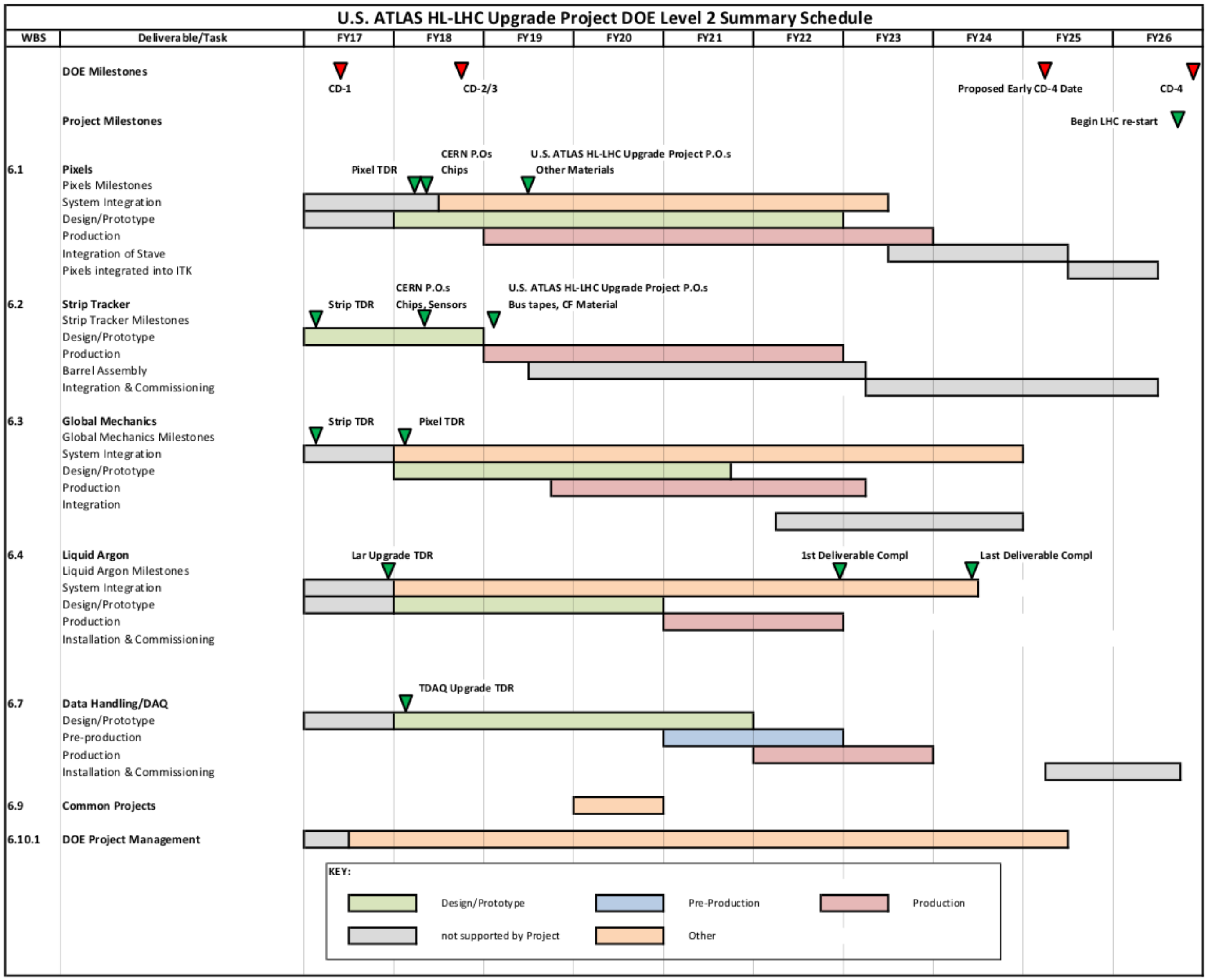
NSF Scope in ATLAS Trigger

ATLAS WBS	ATLAS Item (Scoping Doc)	US WBS	Deliverable	NSF Fraction Design	NSF Fraction Production	
1	**TDAQ System**	**6.8**	**Trigger**	**22% of Trigger Items**		
1.1	**L0 Central**				**-**	
1.2	**L0Calo**				**-**	
1.2.1	FEX				-	
1.2.2	Topo Proc.				-	
1.2.3	Optical Plant	6.8.x.1	L0 Calo	100%	100%	
1.2.4	L0Calo-to-L1Calo				-	
1.3/1.4	**L0 Muon Barrel/Endcap**				**-**	
1.3.1/1.4.1	RPC/TGC Sector Logic				-	
1.3.2/1.4.2	MDT Trigger				-	
	Mainboard				-	
	Mezzanine	6.8.x.2	L0 Muon	100%	100%	
1.5	**L1 Central**				**-**	
1.6	**L1 Global**				**-**	
1.6.1	Aggregator				-	
1.6.2	Event Processor				-	
	Hardware				-	
	Algorithms	6.8.x.3	L1 Global Processing	50%	50%	<== 4 algorithms by US
1.7/1.8	**L1 Track/FTK++**				**-**	
1.7.1/1.8.1	Processing				-	
	Mainboard	6.8.x.4	L1Track/FTK++ Processing	100%	50%	
	RTM				-	
	AM Chip				-	
	Mezzanine				-	
1.7.2/1.8.2	Second Stage				-	
	Mainboard	6.8.x.4	L1Track/FTK++ Processing	100%	50%	
	RTM				-	
	Mezzanine	6.8.x.4	L1Track/FTK++ Processing	100%	100%	
1.9	**DAQ**				**-**	

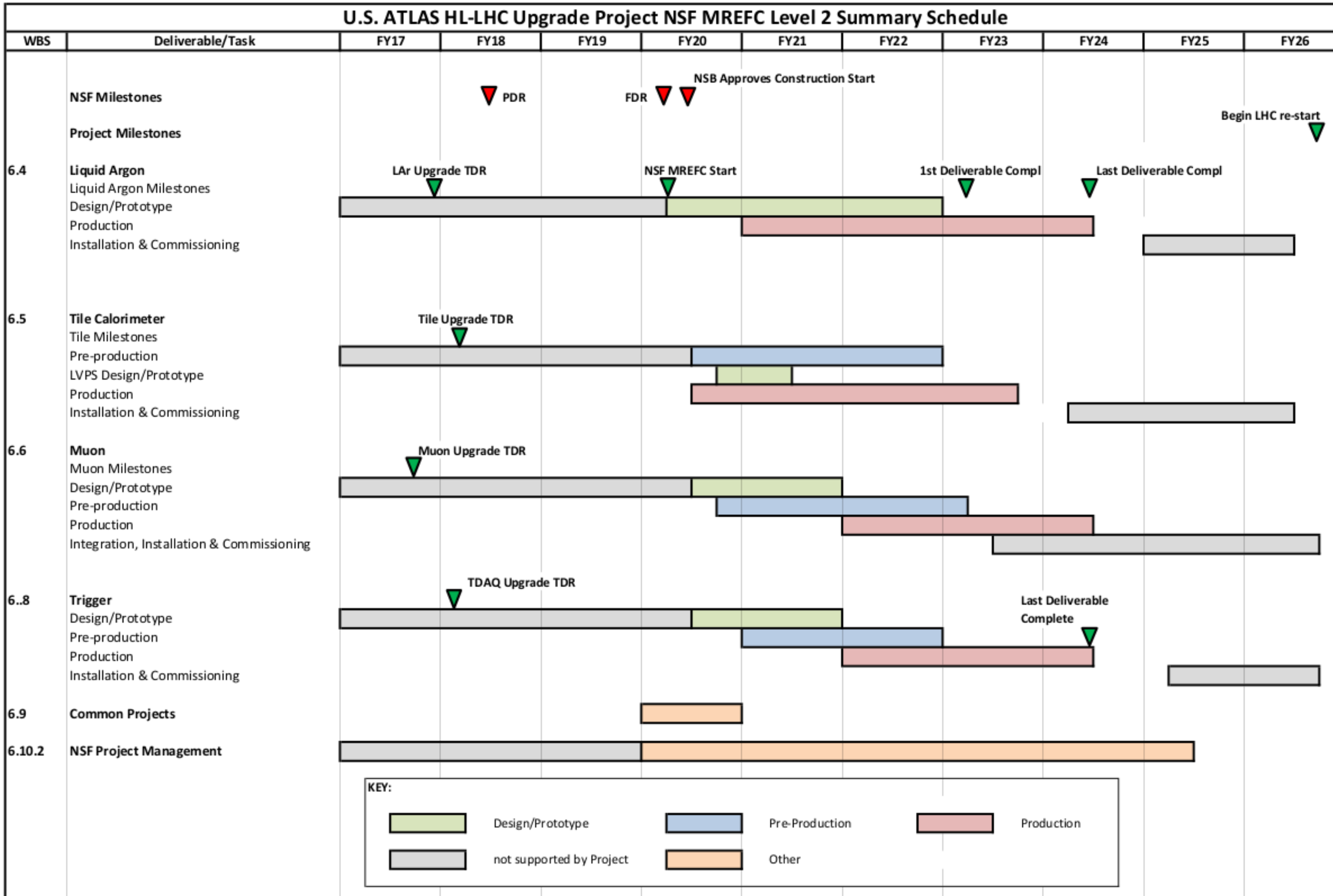
All Upcoming Technical Decisions

System	TDR	Technical Decision (Date)
Pixels	Q4 2017	• η coverage: 4.0 vs 3.2 (Sep. 2016) • layout/mechanics: flat vs inclined modules (Sep. 2016)
Strips	Q4 2016	• layout: move to 4-strip/5-pixel layers (Summer 2015)
Global Mech		• Thermal shield: integrated with Outer Cylinder or not (strip TDR)
Liquid Argon	Q3 2017	• PA/Shaper technology: BNL vs French (TDR) • sFCAL yes or no (Jun. 2016) • HGTD yes or no (May 2017)
TileCal	Q4 2017	• FE chip: 3-in-1, QIE, FATALIC (Sep. 2017)
Muon	Q2 2017	• replace BI chambers with sMDT/RPC (spring 2016) • TDC technology: ASIC, FPGA, VMM-like (TDR) • accessibility of inner chambers (TDR)
Trigger & DAQ	Q4 2017	• architecture: L0/L1 vs L1-only (Summer 2016)

US Schedule (DOE)



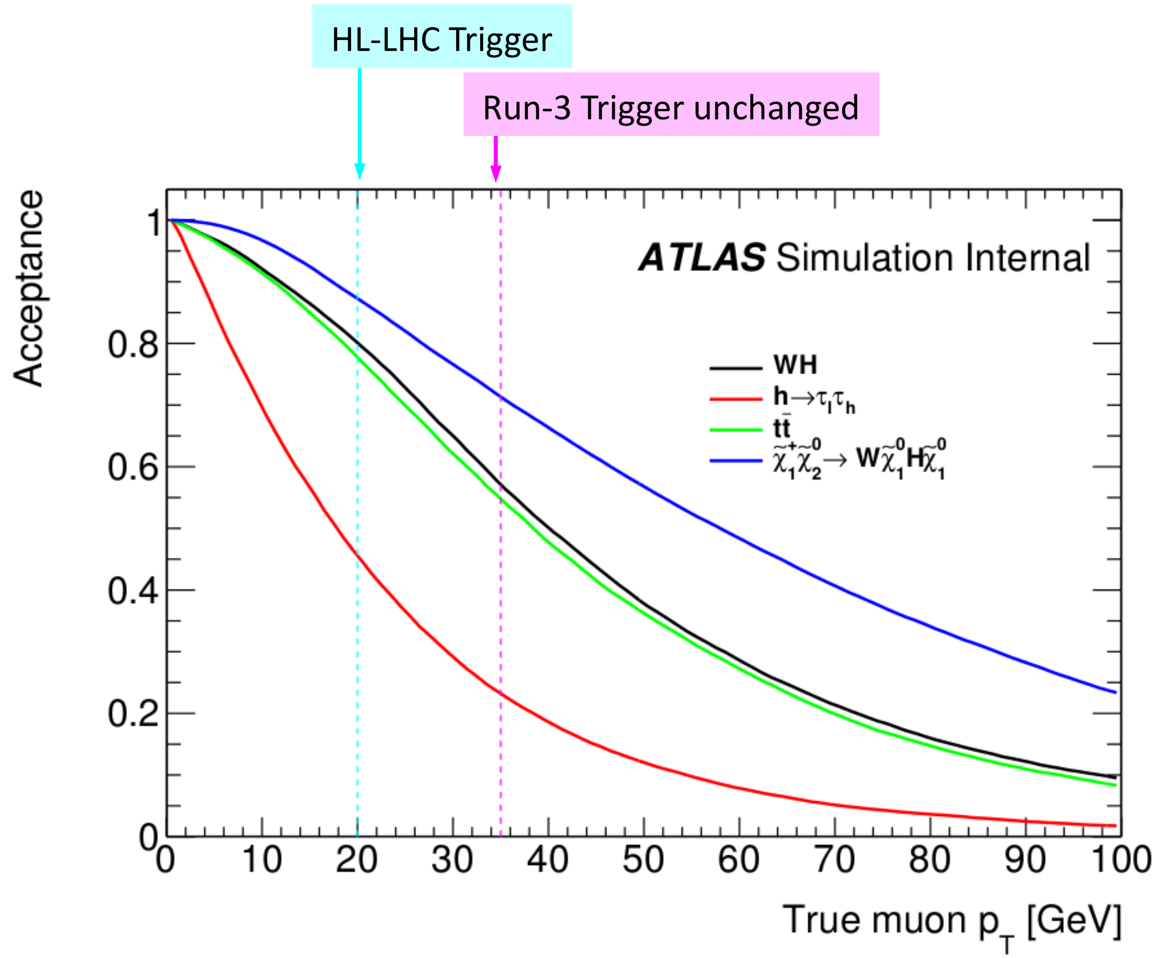
US Schedule (NSF)



Impact of Trigger/DAQ Upgrades

Simplified HL-LHC Trigger Menu

item	Reference		
	p_{T} Threshold [GeV]	$\|\eta\|$	Eff.
iso. Single e	22	< 2.5	95%
forward e	35	$2.5 - 4.0$	90%
single γ	120	< 2.4	100%
single μ	20	< 2.4	95%
di-γ	25	< 2.4	100%
di-e	15	< 2.5	90%
di-μ	11	< 2.4	90%
$e - \mu$	15	< 2.4	90%
single τ	150	< 2.5	80%
di-τ	40,30	< 2.5	65%
single jet	180	< 3.2	90%
fat jet	375	< 3.2	90%
four-jet	75	< 3.2	90%
HT	500	< 3.2	90%
E_T^{miss}	200	< 4.9	90%
jet + E_T^{miss}	140,125	< 4.9	90%
forward jet**	180	3.2 - 4.9	90%



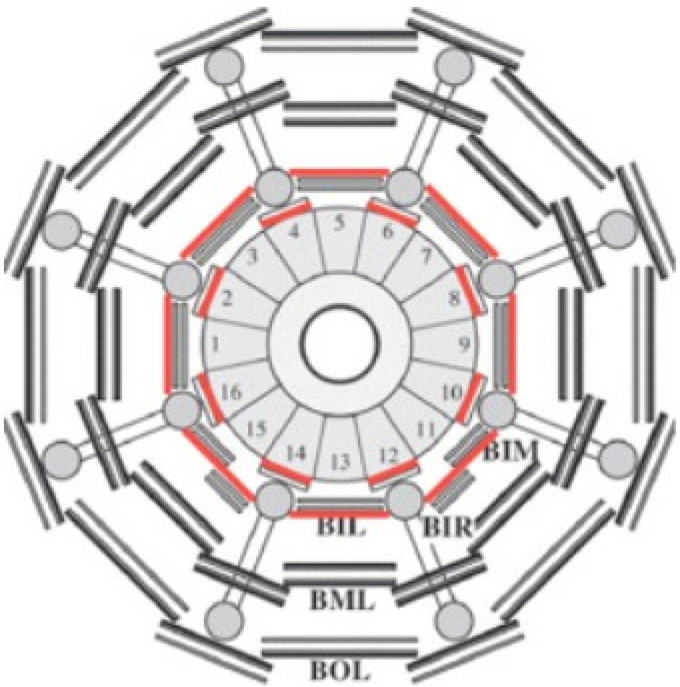
Trigger: Scope Sensitivity

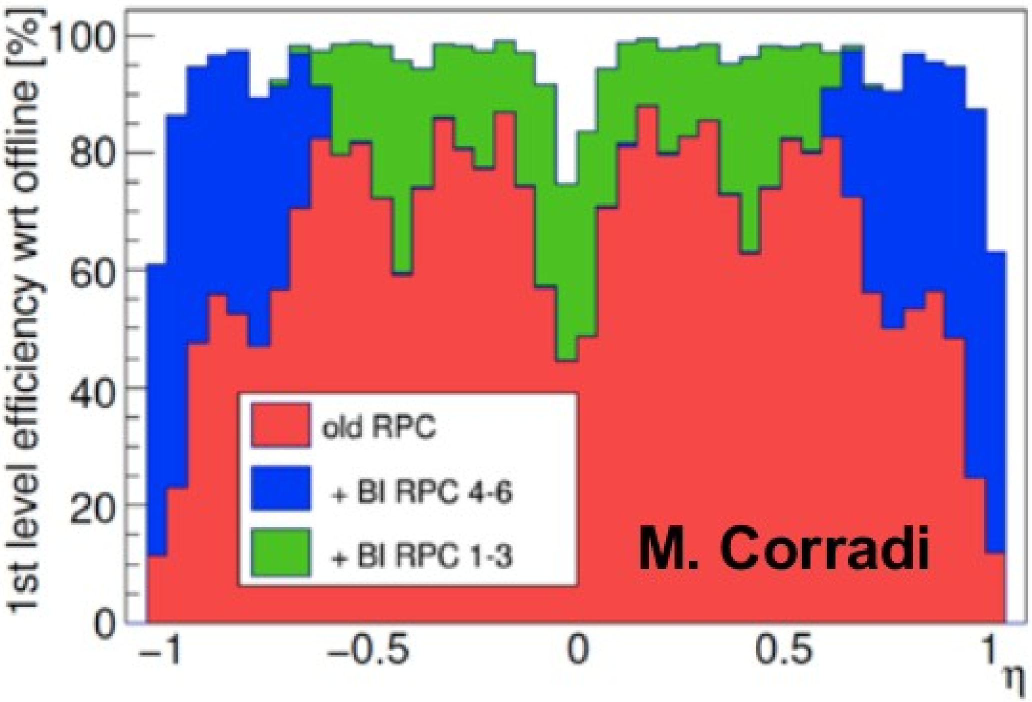
item	Reference			Middle			Low		
	p_T Threshold [GeV]	$\|\eta\|$	Eff.	p_T Thr. Threshold [GeV]	$\|\eta\|$	Eff.	p_T Thr. Threshold [GeV]	$\|\eta\|$	Eff.
iso. Single e	22	< 2.5	95%	28	< 2.5	95%	28	< 2.5	91%
forward e	35	$2.5 - 4.0$	90%	40	$2.5 - 3.2$	90%	-	-	-
single γ	120	< 2.4	100%	120	< 2.4	100%	120	< 2.4	100%
single μ	20	< 2.4	95%	25	< 2.4	80%	25	< 2.4	65%
di-γ	25	< 2.4	100%	25	< 2.4	100%	25	< 2.4	100%
di-e	15	< 2.5	90%	15	< 2.5	90%	15	< 2.5	82%
di-μ	11	< 2.4	90%	15	< 2.4	80%	15	< 2.4	65%
$e - \mu$	15	< 2.4	90%	15	< 2.4	84%	15	< 2.4	70%
single τ	150	< 2.5	80%	150	< 2.5	80%	150	< 2.5	80%
di-τ	40,30	< 2.5	65%	50,40	< 2.5	65%	50,40	< 2.5	55%
single jet	180	< 3.2	90%	225	< 3.2	90%	275	< 3.2	90%
fat jet	375	< 3.2	90%	400	< 3.2	90%	450	< 3.2	90%
four-jet	75	< 3.2	90%	85	< 3.2	90%	90	< 3.2	90%
HT	500	< 3.2	90%	600	< 3.2	90%	750	< 3.2	90%
E_T^{miss}	200	< 4.9	90%	225	< 4.9	90%	250	< 4.9	90%
jet + E_T^{miss}	140,125	< 4.9	90%	150,175	< 4.9	90%	160,200	< 4.9	90%
forward jet**	180	3.2 - 4.9	90%	225	3.2 - 4.9	90%	275	3.2 - 4.9	90%

Trigger Menu: Rate Limits

Item	Offline p_T threshold [GeV]	Offline $\|\eta\|$	Efficiency	L0 Rate [kHz]	L1 Rate [kHz]	EF Rate [kHz]
Isolated Single *e*	22	<2.5	95%	200	40	2.20
Forward *e*	35	2.5-4.0	90%	40	8	0.23
Single γ	120	<2.4	100%	66	33	0.27
Single μ	20	<2.4	95%	40	40	2.20
di-γ	25	<2.4	100%	8	4	0.18
di-*e*	15	<2.5	90%	90	10	0.08
di-μ	11	<2.4	90%	20	20	0.25
e-μ	15	<2.4	90%	65	10	0.08
Single τ	150	<2.5	80%	20	10	0.13
di-τ	40,30	<2.5	65%	200	30	0.08
Single jet	180	<3.2	90%	60	30	0.60
Fat jet	375	<3.2	90%	35	20	0.35
Four-jet	75	<3.2	90%	50	25	0.50
H_T	500	<3.2	90%	60	30	0.60
E_T^{miss}	200	<4.9	90%	50	25	0.50
Jet + E_T^{miss}	140,125	<4.9	90%	60	30	0.30
Forward jet	180	3.2-4.9	90%	30	15	0.30
Total				**~1,000**	**~400**	**~10**

Muon Geometrical Acceptance





Schedule Contingency (Float-DOE)

DOE Deliverables Schedule Float to Installation					
	WBS	Title	Acceptance Test Complete (Mo/Yr)	CERN Required Date (Mo/Yr)	Minimum Float to CERN required date (months)
	6.1.x.1	System Integration	Mar-23	Dec-23	8
	6.1.x.2	Pixel Mechanics	Mar-21	Apr-22	12
	6.1.x.3	Services	Sep-22	Jul-23	9
Pixels	6.1.x.4	Local Supports	Mar-23	Oct-23	6
	6.1.x.5	Modules	Jun-22	Jan-23	6
	6.1.x.6	Off-Detector Electronics	Mar-23	Oct-23	6
	6.1.x.7	Support	Sep-23	Dec-23	2
	6.2.x.1	Stave Core	Sep-21	Dec-21	3
Strips	6.2.x.2	Readout/Control Chips	Sep-21	Dec-21	3
	6.2.x.3	Modules & Integration	Sep-22	Dec-22	3
	6.3.x.1	Integration System Test	Sep-24	N/A	-
Global Mechanics	6.3.x.2	Outer Cylinder & Bulkhead	Jun-21	Nov-21	6
	6.3.x.3	Thermal Barrier	Jun-21	Nov-21	6
	6.3.x.4	Pixel Support Tube	Dec-22	Apr-21	3
Liquid Argon	6.4.x.4	System Integration	Mar-24	Jan-25	10
	6.4.x.5	PA/Shaper	Sep-22	Jul-23	9
	6.7.x.1	L1 Global Aggregator	Sep-22	Dec-24	26
Data Handling/DAQ	6.7.x.2	L1 Track Input	Sep-23	Dec-24	14
	6.7.x.3	DAQ/FELIX	Sep-23	Dec-24	14
	6.7.x.4	RoI Distributor	Sep-23	Dec-24	14

Full Scope Contingency Summary

System	Scope Contingency	Savings
6.1 Pixels	reduce: LV power, supports, stave flex, bump bonding, modules	$3.2M
6.2 Strips	deliver less cores/modules/staves	var
6.3 Global Mech	thermal barrier	$0.3M
6.4 Liquid Argon	less firmware for BE produce less FEB2/Otx/BE Mbs drop PA/shaper	$1M $1M $1M
6.5 TileCal	drop LV box assembly	$0.4M
6.6 Muon	drop production of TDC (design only)	$1.2M
6.7 DAQ/Data	produce less L1Track/FTK++ RTMs	$0.7M
6.8 Trigger	drop 1 L1Global Algorithm produce less L1Track/FTK++ MBs	$0.4M $1.1M

Full Scope Opportunity Summary

System	Scope Opportunity	Cost	Benefit/Motivation
6.1 Pixels	• buy 20% of sensors (cf 0%)	$1.7M	modules use US sensors
6.2 Strips	• none	---	main areas assigned
6.3 Global Mech	• common electr. (DAQ)	$1.5M	US experience here
6.4 Liquid Argon	• sFCAL • HGTD	$5.4M $5.3M	US-led effort significant US leadership
6.5 TileCal	• produce all LVPS (cf 50%)	$1.1M	reduce external dependency
6.6 Muon	• contribute to power supplies	$2M	may be needed
6.7 DAQ/Data	• prod all L1Global aggr's (cf 50%) • 30% FELIX card prod (cf 15%)	$0.4M $0.5M	reduce external dependency all needed for ITK integration
6.8 Trigger	• add 1 L1Global Algo	$0.4M	US expertise here